



PROPOSAL TO DEVELOP
MICROELECTRONIC CHIP
FABRICATION FACILITIES
IN ALBERTA

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Microelectronics Steering Committee
Alberta Research Council

**PROPOSAL TO DEVELOP MICROELECTRONIC CHIP
FABRICATION FACILITIES IN ALBERTA**

EXECUTIVE SUMMARY

1. This proposal aims to initiate the development of microelectronic chip fabrication facilities in Alberta. It recommends that the Alberta Research Council and the Province take action at once.
2. Microelectronic chip design and fabrication facilities are consistent with diversification of the Province's economic base, and the need to quickly penetrate the new technologies in a significant way, while building upon existing technological and economic strengths.
3. Primary benefits of chip design and fabrication facilities are a) to enhance the competitive position of existing industries since use of microelectronics chips results in cheaper, more marketable systems b) to promote the development of new industries associated with microelectronic chip design and fabrication c) to establish a technological nucleation center serving to attract further investment and expertise.
4. Activities in Alberta associated with energy, agriculture, telecommunications, medicine and education offer potentially attractive markets for custom microelectronic chips and their application as sensors, instruments and special processors.
5. Computers are now required to cope with the design and construction of complex electronics and software systems. A chip fabrication initiative can attract new industries associated with software engineering and chip design.
6. Chip design and fabrication facilities also provide opportunities a) to exploit strengths of Alberta's universities and technical institutions b) for many Canadians abroad, with microelectronics and software skills, to return to Canada.
7. Security of microchip supplies is a prevailing and justifiable concern of industry. An indigenous capability to design and fabricate microchips provides the essential stability and security for industries to undertake lucrative contracts dependent upon microelectronics.
8. Costs of modest design and fabrication facilities are expected to be \$50 million over six years. About 75 percent of costs are directed towards industrial microchip fabrication (low volume custom chip manufacturing facility). This portion is proposed to be funded primarily by industrial and venture capital funds. The remaining 25 percent is directed towards associated research and development (a laboratory facility), and proposed to be funded by government. For this scale of facility, the accumulated cash flow is projected to be positive after six years.
9. Industrial leadership towards exploiting the commercial advantage of microelectronics and software systems is the key factor for success. University research, the development of skilled manpower, and supporting policies and incentives of government are important and complementary. The organization of the fabrication facilities involves existing agencies.

RECOMMENDATIONS AND PROPOSED ACTIONS

RECOMMENDATION 1:

It is recommended that Alberta adopt a policy to take major initiatives in the microelectronics and software sectors, for development of an industrial base with significant strength and overall stability.

RECOMMENDATION 2:

It is recommended that microelectronic chip design and fabrication be developed as a cornerstone in Alberta's microelectronics and software position.

RECOMMENDATION 3:

It is recommended that the chip fabrication facilities be jointly sponsored by industry, university and government with each sector making their own unique contributions to the facilities.

RECOMMENDATION 4:

It is recommended that Alberta proceed with the intent of coordinating with other national and international initiatives towards the development of chip fabrication facilities. It is further recommended that the development of Alberta-based fabrication facilities encourage, but not depend upon, financial support from out-of-province agencies.

RECOMMENDATION 5:

It is recommended that the microchip design and fabrication facilities continue to be arranged under the auspices of the Alberta Research Council.

It is recommended that the Alberta Research Council's position on microchip design and fabrication facilities continue to be developed by a Microelectronics Steering Committee, taking into account the provincial, national and international nature of microelectronics and software activities.

This proposal seeks support for the development of microelectronics chip fabrication facilities by:

- a) Agreement in Principle on the above recommendations.
- b) Agreement of the Alberta Research Council to establish liaison with Alberta Economic Development to develop a business plan for the fabrication facilities.

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INTRODUCTION

This document aims to initiate the development of microelectronics chip fabrication facilities in Alberta.

At the request of representatives from Alberta's industrial, university and government sectors, a Microelectronics Steering Committee was established to develop a proposal for microchip fabrication facilities. The Steering Committee (members are listed in Appendix 1) operated under the auspices of the Alberta Research Council. Additional input was gained through discussions with:

- National Research Council
- National Science and Engineering Research Council
- University of British Columbia
- University Coordinating Committee - National Microelectronics Facility
- Microelectronics industries across Canada.

The Steering Committee extends sincere appreciation to many key individuals and their organizations who provided extensive input to this proposal.

In PLANNING FOR AN INFORMATION SOCIETY-TOMORROW IS TOO LATE (Science Council of Canada - Summary Report No. 33), Federal and Provincial governments are urged to become active participants in preparing for an information society. "Canada's choice to support or ignore the revolution in microelectronics will affect many sectors of our economy. The application of computer systems to the mining and harvesting of our natural resources is essential if we are to remain competitive in a world market. Our agricultural, fishing and forestry industries must move to automate their tractors, milking systems, irrigation, crop spraying and fishing fleets or risk being underpriced by other nations. Already a world leader in communications satellite technology, Canada must continue its research in remote sensing and automated systems to keep our resource sectors competitive with other

world suppliers. _____ Canada's custom chip manufacturing capability is almost nonexistent, although access to custom chips is essential for the growth of the Canadian electronics industry. Without such a manufacturing capability in Canada, our industry will remain dependent on foreign sources. If more imported chips are used in Canadian products, employment and revenues will be created abroad with resulting unemployment and factory closures at home."

Strong support has been expressed for microelectronic chip design and fabrication facilities in Alberta. The Steering Committee therefore recommends that the Alberta Research Council and the Province take action on this proposal at once. Agreement on this proposal would provide the funds for a detailed plan for the chip fabrication facilities.

This proposal is presented in two parts. The first part outlines how microelectronics initiatives are consistent with provincial and national objectives. Opportunities and benefits, strategic options and an action plan for developing a microelectronic chip fabrication facility are discussed. The second part outlines preliminary views on the character of the fabrication facility. Technological aspects, connecting programs, and financial and managerial issues are considered. Background papers in Appendix 2 were contributed by some Steering Committee members and provide further details on microchip design and fabrication.

PART 1: CHIP FABRICATION FACILITY - DEVELOPMENT STRATEGY

Background - Microelectronics and Software

Some of the more visible devices of the microelectronics "revolution" are electronic calculators, quartz-controlled timepieces and home computers. The basis for these types of developments lies in semiconductors (microelectronic chips) and the way they are instructed to perform their tasks (software). Microelectronic chips can be characterized as combination of tens or hundreds of thousands of transistors in a two or three dimensional silicon structure. Complex electronic processing can be accomplished in a single, small, reliable, mass produced product. Electrical signals travelling on microchip circuits can be compared to cars travelling on highways. Using this comparison, chips of the 1960's are similar in complexity to the street layout of a small town, while chips of the 1980's are similar in complexity to street networks of urban density covering the entire North American continent. This burst in technology is expressed by the words Large Scale Integration (LSI) and Very Large Scale Integration (VLSI), in the context of integrating the capability of many transistors on microelectronic chips.

The fabrication of microelectronic chips cannot be separated from the requirement for powerful and complementary design tools. Consequently, another important component in exploiting the capabilities of LSI and VLSI technologies lies in software. Software plays a central role in microelectronics developments, since it is essential

1. to manage the complex chip design, simulation, and testing processes
2. to instruct the chips how to perform their tasks.

Both software design and chip fabrication are included in the proposed facilities.

Provincial Objectives

One of the principal objectives of the Alberta Government is to foster economic development, with a view to reducing the province's dependence on the export of unprocessed resources. While building upon the vitality and existing strengths of the agriculture and energy sectors, opportunities leading to diversification of the province's economic base and to balanced growth can be exploited as part of the economic plan. Another increasingly important aspect of good economic thinking is the recognition of intellectual property as a resource. In high technology and microelectronics, knowledge and experience will determine our impact and interaction with external markets.

The challenge that Alberta now faces is to diversify its industrial base by using existing economic and technological strengths. One of the ways is to become even more efficient and intelligent agriculturalists and energy producers through the application of new technologies, while developing industries more closely connected to the new technologies.

Microelectronics and software present opportunities for diversification in activities ranging from microchip fabrication to software engineering, human-machine interfaces and knowledge-based systems. Microchip design and fabrication facilities meet the challenge of diversification based upon existing strengths because:

1. Specialized microelectronics chips produced by the facilities have immediate applications in existing industries.
2. Microelectronics chips are characterized by energy efficiency, reliability and portability. Industries using such devices will have a competitive advantage.
3. Design and fabrication services represent a product in their own right, and are associated with a proven growth industry (new industries).

The Setting

International

Almost every industrialized country in the western world has examined the impact of the emerging "microelectronics and software" society, especially the extent to which increased reliance on imported microchips can lead to increased economic vulnerability. An important feature in many of these countries is coordination of efforts among the industrial, university and government sectors. The competition between nations is strong, and trade barriers in the microelectronics area are being constructed to protect national interests. Security of supply in relation to microelectronics know-how and specialized devices is not just concern, it is a reality. As an illustration, in February 1983, a professor at the University of Calgary received the following in a letter from a colleague in California:

"I'm sorry to inform you that I cannot provide you with our VLSI tools distribution. Our Department of Defense sponsors prohibit us from making any distributions outside the U.S.A. As you are probably aware, the U.S. Congress has been worrying a lot lately about a perceived loss of the country's technological lead, and the restrictions are a result of this worry. Although I don't support this "solution", the terms of our research contracts require us to enforce the restrictions. Unfortunately, it does not appear likely that the restrictions will be lifted anytime soon. I apologize for any inconvenience that this will cause you."

A reasonable response for Canada and Alberta is to develop an indigenous capability in microelectronics and microchip (VLSI) fabrication. This is necessary for us to continue with the benefits of being an "industrialized country", and to avoid an unfavorable balance of trade position in high technology products.

Various countries with traditional technological strengths including Japan, United States, Britain, France and West Germany have embarked on massive programs in microelectronics, with differing types of coordination among university, industrial and government sectors. Details of these programs are spelled out by Hill et al. (Appendix 2) and by the Science Council of Canada in Report #33 "Planning for a New Information Society - Tomorrow is Too Late".

Microelectronics activities are now occurring in many countries. This is illustrated by programs in Sweden, Australia, Austria, Yugoslavia, Ireland, Korea, the Netherlands, Belgium, and to some extent in Canada. The Netherlands provides an interesting example. With a strong (and traditional) need to capitalize on intellectual know-how, this small country has developed two major VLSI research and development centers in connection with technical universities.

National

According to Science Council Report #33, Canada is barely holding its own in the International race to exploit new technologies, in spite of strengths in its university system, and some corporate successes in the area of telecommunications (Mitel and Northern Telecom are examples). The major differences between Canada and other western industrialized countries are three-fold: 1) in Canada there is less integration of efforts in microelectronics which could ensure a presence in home and foreign markets 2) governmental support in Canada for the new technologies is small compared to that provided by other countries and 3) unlike other western industrialized countries, Canada has had a unique relationship with the technologically advanced United States. This relationship with United States may no longer hold in microelectronics since the sharing of information and common goods and services cannot be relied upon. It is essential that this recent change be accounted for in our industrial strategies. Alberta and Canada must be prepared to stand behind the principles of free enterprise and with appropriate government policies, leadership, and

incentives, begin to place ourselves in a more competitive position. As part of the required coordination and support related to the microelectronics and software sectors, the Science Council in its Report #33 recommends that industry and government collaborate to develop and maintain a custom silicon chip design and manufacturing capability.

Alberta

As a consequence of the energy boom of the 1970's, Alberta has the resources to take a lead role in Canada's future economic development. The establishment of Bell Northern Laboratories and Northern Telecom in the province also provides a base for further development of the electronics sector. These recent initiatives supplement an electronics industry base of about 150 generally small companies. Larger enterprises such as Nova, Petro Can, and AGT, together with the smaller firms, may seek to improve their competitive capabilities based upon the new microelectronics and software technologies. In a broader context this is manifested by the recent formation of the Electronics Industries Association of Alberta.

The strengths of Alberta's university system are significant in areas of electrical engineering, computer engineering and computer science. The University of Calgary, for example, is prominent in software technologies connected to human-computer interface and distributed software development environments. Recently, both the University of Alberta and University of Calgary have acquired state-of-the-art CAD/CAM systems which provide the potential for strong capabilities in the design of complex microelectronic chips. They are also developing teams directed towards the design of microelectronic chips and their applications as sensors, instruments and special processors. These university initiatives are discussed in greater detail in Part 2, where their relation to the fabrication facility are outlined.

The Alberta Microelectronics Center (AMC) at the University of Alberta acts as an important interface between industries and universities. Of several such centers in Canada, AMC represents a significant capability through its active education and technological assistance programs, to enhance the technological capabilities in the province.

Another important development in the emerging microelectronics strategy for Alberta is the new direction the Alberta Research Council has taken to become heavily involved in stimulating high technology growth in the province. The Alberta Research Council has a key role in advising the government on scientific matters and in promoting responsible economic development through the use of science and technology. In this context, the Research Council is in position to initiate the chip fabrication facility on behalf of industry, university and government. One of the ways the Research Council advises government is through the Cabinet Committee on Research and Science Policy, and its associated Advisory Committee. Because of the provincial-wide implications of these facilities, a preferred avenue for acceptance of this proposal is through these committees.

Opportunities and Benefits

Following the theme advanced earlier, strengths within Canada can be used to advantage with a diversification and expansion strategy based upon the new technologies. As a result of past achievements, Canada is well-placed to become one of the most efficient producers of energy, agricultural and forest products. Moreover, Canada is a leader in many aspects of geophysical exploration, remote sensing and telecommunications.

For such industries, as examples, to continue as a strength in Canada, the use of new systems design and construction concepts is essential. For example, computers are now required to cope with the design and construction of complex electronics and software systems. This represents an opportunity for new industries to supply the demand

for new software and to apply this software to the development of new systems.

The development of new systems in the industrial environment is closely connected to microchip fabrication. The traditional approach was to connect separate components, including simple transistors, integrated circuits, and complete computers to form complete systems. Due to advances in microelectronic fabrication, complete systems are now commonly found on single chips, which can be modified to provide the flexibility previously restricted to systems of interconnected components (see Hill et al., in Appendix 2 for a detailed discussion). The speed, energy efficiency, reliability, and portability of the new systems provides a significant competitive advantage. Opportunities for systems produced with the traditional approach will be severely limited. Therefore, the ability to translate existing design expertise into design and production of microelectronic chips is essential. Specially-designed chips referred to as custom or semi-custom chips) provide an entry into preferred market areas, or market 'niches'.

Applications of microelectronics technologies and sensors, based upon the specially designed and fabricated chips, in agriculture alone range from crop spraying, to irrigation, drainage regulation, and animal feeding and milking systems. For example, herbicide spraying systems which use appropriate sensors and microelectronics to maintain uniform application of chemicals by accounting for chemical strength, nozzle pressure and motion of the spraying equipment, have unquestionable utility and marketability. In energy, new analyzing tools, graphical devices, field installed processors and transducers represent opportunities to market new products that are related to our existing know-how. The utility of remote terminal units for pipeline monitoring and control (based on VLSI technology) represent another example of markets for microchip design and fabrication technologies. In telecommunications, telephones combining information display with voice transmission (which are likely to replace telephone books) will require specially designed microelectronic chips. Other existing

strengths and knowledge in medical research, climatic conditions, information distribution and education delivery provide a great potential for application of microelectronics systems, characterized by custom designed microchips.

The above applications are noted in relation to existing industries. However, the most important long term payoff may be through diversification industries or those developed as a consequence of microchip design and fabrication initiatives. Such industries could a) sell design and fabrication services and b) sell know-how associated with custom chip design and fabrication.

An accessible fabrication facility for Canadian and Albertan industries, large and small, means significantly greater opportunity in the market place. Primary design and fabrication centers in Canada are associated with major industries. There are no open fabrication facilities catering directly to small industries. Such a capability in Alberta would also have the effect of attracting new industries.

The current recession has provided an opportunity or "breathing space" for Canada and Alberta to enter the microelectronics environment. Growth of existing competitive industries (on an international scale) is now limited. This means greater availability of manpower; a situation that will change when the current recession ends. It is also reasonable to speculate that when the recession ends, chip design and fabrication facilities in other countries, which now supply chips to Canadian industries, will supply their own vertically integrated organizations first. With security of supplies in question, it is difficult to both obtain and maintain many lucrative contracts depend heavily upon microchips. These arguments show that investment during the recession (an action restricted to the wealthy) provides an entry point from which Alberta can diversify and be industrially competitive.

Major industries such as Bell Northern Research, already located in Alberta, are already associated with microelectronics technology and can be of significant advantage in both helping with and benefiting from the development of a chip fabrication facility. Moreover, chip design and fabrication facilities are needed to exploit the capability of the universities in Alberta. This is evidenced by the computer engineering and sensor technology programs getting underway at the University of Alberta, and the microchip design programs at the University of Calgary. Both of these universities have needs for microchip fabrication facilities (see James, C.R. et al., Appendix 2).

While many scientists and engineers, especially those in the consulting industry, are suffering from unemployment, the demand remains for computing scientists, computer engineers, electrical engineers and physicists with microelectronics and software skills. Appropriate fabrication facilities will provide an opportunity for many Canadians abroad, skilled in microelectronics and software, to return to Canada. Since microchip fabrication and design are the two key factors associated with microelectronics system developments, an investment in such facilities is likely to place Alberta in an enviable position in Canada to attract the engineers and scientists with microelectronics and software skills.

The growth of the microelectronics and software sectors has also created new opportunities for Alberta. Alberta can now compete in advanced systems design due to software-based advances in microchip design. In the last two years CAD systems have become available which permit a broad cross-section of researchers, industrial engineers, students and professors to design advanced microchips cost effectively. Previously such chips could only be designed by a few individuals in the originating laboratories of this new technology. This advance in technology presents an ability to enter the microelectronics and software age in an aggressive fashion. There is also a readiness which is based upon an increasing maturity in the university and industrial environments. Mitel, Northern Telecom and

similar successful companies in microelectronics and software have experienced dramatic growth in the past decade. Several small industries in Alberta are now developing and producing electronics products calling for custom or semi-custom microelectronics chips. This ability and readiness of the various sectors to take advantage of custom microchip-based systems and their fabrication is of increasing necessity. Those industries now producing systems based on the old technology of interconnecting simple microchips are currently facing newer, cheaper, more marketable systems based on the custom designed LSI and VLSI technologies. The future is such that if such new electronics systems are not built in our own fabrication plants, Alberta and Canadian industries will find themselves buying entire systems - resulting in continued stagnation of our industrial sector.

There are further specific opportunities for Alberta. A national initiative aims to see chip design and fabrication for the university and industrial sectors coordinated on a national scale. Alberta can play a major role. This is another opportunity whereby investment would have a snowball effect, by attracting further investment, creating new industries, developing existing industries and thereby placing the province in an enviable "central" position (entrepreneurial nucleation center) of the high technology arena.

Strategic Options and Recommendations

This section documents a strategy for rapid entry into the high technology microelectronics and software environment, with specific consideration of microchip fabrication facilities in Alberta.

RECOMMENDATION 1

It is recommended that Alberta adopt a policy to take major initiatives in the microelectronics and software sectors, for development of an industrial base with significant strength and overall stability.

There is momentum in the microelectronics and software sectors elsewhere, and Alberta may be most industrially competitive by taking advantage of existing know-how and by seeking special "niches" where risks are low and benefits are high. These niches are connected mainly to applications in the energy, agricultural and communications sectors, and to new industries associated with microchip design and fabrication. This suggests that Alberta move into the area of custom VLSI and LSI chip design and fabrication, where there is very little competition in Canada. The alternative to an aggressive action plan is to take no action, which is contrary to the diversification strategy of the province. Because of the well-defined growth in the microelectronics sector, a "wait and see" strategy is a losing strategy. Only timely action can now provide an entry point from which commercial advantage can be gained.

RECOMMENDATION 2

It is recommended that microelectronic chip design and fabrication be developed as a cornerstone in Alberta's microelectronics and software position.

The principle of this recommendation lies in the facts that

- a) chip design and fabrication is an integral part of microelectronics systems development
- b) open chip design and fabrication facilities are required in Canada and if not built in Alberta may not be built anywhere. Without open design and fabrication facilities, the competitive positions of existing and emerging industries, which require computer and microelectronics systems, are compromised.
- c) provincial commitment to fabrication facilities would illustrate Alberta's serious intention to enter the information - based society and attract further investment to the Province.

Investment in chip fabrication facilities, as a priority, means the effective development of special chip-based systems. These systems will find virtually immediate application within the energy, agricultural, communications and medical sectors. The applied or mission-oriented nature of these activities implies emphasis on other programs which are directed towards systems design, design tools, simulation, and sensor technologies; these technologies are under development at the Universities of Alberta and Calgary, and at the Alberta Research Council.

RECOMMENDATION 3

It is recommended that the chip fabrication facilities be jointly sponsored by industry, university and government with each sector making their own unique contributions to the facilities.

The proposed facility aims to take advantage of existing technology with provision for keeping the technology updated. Custom chips designed and manufactured by the facility would be used by industries and universities (in development of skilled manpower and new technologies). University requirements are connected mainly to research and development and to the training of skilled manpower. Further development of skilled manpower is a long term investment, so government and industrial support directed towards microchip experimentation in university laboratories is needed. Finally, small industries must have access to fabrication and design facilities, but currently do not have resources to support their cause; government support on their behalf is required. The industrial component of the facilities would naturally be profit oriented.

The analyses in Part 2 and the contribution by J. Robson (Appendix 2) illustrates that over a wide range of possibilities, from a very low level of effort to highly complex facilities, reasonable facility costs are about \$50 million over six years. This includes laboratory facilities for research and development and a low volume production line suitable for fabricating custom chips. Taking into account the need for small industries to gain access to the profit-oriented low volume production line, and all industries to gain access to the research and development portion, the principle of government, university and industrial sponsorship is proposed. Venture capital programs may provide the basis for financing the profit-oriented portion of the facility.

RECOMMENDATION 4

It is recommended that Alberta proceed with the intent of coordinating with other national and international initiatives towards the development of chip fabrication facilities. It is further recommended that the development of an Alberta-based fabrication facilities encourage, but not depend upon, financial support from out-of-province agencies.

Because of the relatively limited manpower and technological resources in Canada, working in conjunction with other governments, industries, and universities outside Alberta is desirable to ensure a successful facility. In this regard, Alberta can take advantage of momentum already developed or developing outside the province. At the federal level, NRC and NSERC are paying close attention to a university initiative which aims to originate a national-based chip design and fabrication facility. Moreover, the use of chip design and fabrication capabilities extends beyond the boundaries of Canada. The development of technology links to existing companies can also contribute to the effectiveness of Alberta-based fabrication facilities.

Alberta must be prepared to proceed on its own so that development of fabrication facilities can begin at once. This principle, together with the intent and commitment to coordinate with others, is considered to be the most effective strategy for Alberta to gain a favorable position in the industrially-based microelectronics and software sector.

RECOMMENDATION 5

- A. It is recommended that the microchip design and fabrication facilities continue to be arranged under the auspices of the Alberta Research Council.
- B. It is recommended that the Alberta Research Council's position on microchip design and fabrication facilities continue to be developed by a Microelectronics Steering Committee, taking into account the provincial, national and international nature of microelectronics and software activities.

The Alberta Research Council is a major scientific and technological authority in Alberta with administrative and managerial connections to universities and industries. The intent of this recommendation is supported by the need for coordination of the three sectors in developing a chip fabrication facility, together with the Research Council's mandate to promote responsible economic development of the province through the use of science and technology.

Proposed Actions Based Upon Recommendations

From the foregoing sections it is apparent that the development of a microchip fabrication facility is a program of significant magnitude. The costs of modest facilities are expected to be \$50 million over 6 years, with both profit oriented and research and development components. There are a number of important details to care for which are connected to administrative, managerial, financial and technological structures. Negotiation with out-of-province interests is important to the success of the facility, especially with respect to manpower and technological processes. Agreements on intellectual property, patent rights and eligibility for access to the facility are required. In this regard, consultants are needed to advise on the development of the facilities.

With an urgent need to establish a position in microelectronics and software in Alberta, it is important to move quickly.

This proposal seeks support for the development of microelectronics chip fabrication facilities by:

- a) Agreement in Principle on the recommendations presented in the preceding section
- b) Agreement of the Alberta Research Council to establish liaison with Alberta Economic Development to develop a business plan for the fabrication facilities.

PART 2: CHARACTER OF THE MICROELECTRONIC CHIP FABRICATION FACILITY

It was noted in Part 1 that the design of electronics-based systems is now becoming indistinguishable from chip design and software design. In this regard "chip fabrication facility" refers to the design, simulation and construction of microelectronics chips. Design and simulation of microchips are fast becoming the central issues connected to successful electronics systems.

Computer-Aided-Design

Using Computer-Aided-Design tools to design microelectronics systems essentially entails the setting out of descriptions for circuit layout on the chips, optimizing for space, flexibility and reliability. Custom chips are sometimes designed for a singular or special function. Semi-custom chips have a base design, and are tailored to meet special needs only in the latter stages of the fabrication process. Chip designs can be accomplished on commercial CAD systems, such as the ones at the Universities of Alberta and Calgary and on mini-computers such as the VAX 11/750. The simulation of microchip capabilities is a principal activity associated with the design and fabrication of electronics-based systems. Simulations provide performance data against which actual tests of newly-fabricated chips are made. These performance data can be used to improve upon both the design of the chips and the fabrication processes, leading to the most competitive electronics-based systems. As part of the proposed facility, a significant design and simulation capability for custom and semi-custom chips is required, and must be available to universities in their research and training programs, and to companies to develop their products.

As a result of the newly developed CAD capabilities, it is recognized that extensive research, education and training programs are required to assist design engineers and students in using these new techniques. The universities in Alberta, the institutes of

technology and the Alberta Microelectronics Center (AMC) are logical locations for the training programs.

Extensive CAD facilities, for use in conjunction with chip fabrication, should be located in both Edmonton and Calgary, with close connections to the fabrication plant. These design facilities can be located within the university and possibly within the industrial environments. Joint university-industry access to design facilities can be coordinated by the AMC. In this context, and with regard to education and training outside the university environment, the implication is that AMC may require more than one office in the province and an expanded mandate.

Because of the coordination of design facilities on a national scale, CAD must be considered in conjunction with the interests of other universities and industries across Canada. This coordination is explored in a later section of this proposal.

In the chip fabrication environment, significant efficiencies can be gained from having the design and fabrication facilities in close proximity. This minimizes the turn-around time between chip design and fabrication (often an iterative process) and maximizes interaction between designers and process engineers responsible for fabrication. In the future, however, the design and fabrication processes will become integrated to some extent and the design process will be less of a bottleneck in development of electronics systems. Engineers will be able to specify designs at the functional level, say, which will result in automatic specifications of logic, circuit and even the mask level geometries (signal routing) on the microchip. This goal, however, can only be achieved through major research efforts directed towards design tools.

Fabrication

Fabrication of microelectronics chips involves complex processes in constructing the tiny circuit elements using silicon as the primary

base. Processes include mask making, lithography, diffusion, epitaxy, ion implantation, metalization, assembly and testing. These processes have been the subject of extensive research and development. They continue to be perfected, often through simulation techniques, in the interests of producing even more powerful and marketable chips.

The fabrication program of the facility can be separated into three parts, each with a particular uniqueness but not mutually exclusive. These three parts are described as "lines" (taken from assembly "line"); they are a) laboratory line b) low volume manufacturing line and c) high volume manufacturing line.

Laboratory Line

This line is used by researchers and process engineers to concentrate on new equipment, advanced process technology, new devices and circuits. In this research and development portion of the facility, the process parameters can be adjusted in response to new research and engineering ideas. It provides a means to keep the low volume manufacturing line updated through the development of new processes and special types of chips. In addition, the laboratory line provides a training ground for students, technicians and operators, whose skills can then be used by the manufacturing line. The laboratory line can be used to run very small volumes of prototype chips. Its primary use would be in the testing of student LSI and VLSI chip designs, and by university faculty members.

In summary, the laboratory line represents research and development, or the long term investment aspect of the fabrication facility, and is of primary importance to industry.

Low Volume Manufacturing Line

The low volume manufacturing line can satisfy, in the short term, most chip requirements of industries and universities in Canada, apart from the high volume requirements of the largest electronics

companies. The processes for fabrication are fixed (as compared to the laboratory line) in the sense that different design instructions are used to produce custom and semi-custom chips without altering the actual fabrication process. It is expected that this low volume line could handle 100-200 new designs per year, and based upon these designs could produce about 2000 chips per day. The line falls within the interests of small industries and universities because it can handle and test new designs, while being able to produce modest production quantities of chips. As an initial move into microelectronics and software, the laboratory line and low volume manufacturing line are most appropriate for Alberta.

Large Volume Manufacturing Line

Large volume standard product manufacturing (for example memory and microprocessor chips) could eventually be considered further, if the security of Canadian supplies becomes jeopardized. As well as being a primary source, this line also represents a second source of chips - a role of major importance to industry. However, in view of both Japanese and United States competition, commercial success for such a venture at this time would be unlikely.

Connecting Programs

The chip fabrication facilities only include the actual design, fabrication, simulation and testing of microelectronic chips. There are, however, many programs necessary and complementary to the fabrication facility, for a successful high technology industrial development plan. They are listed below.

New Technologies

This program is in some ways an adjunct of the laboratory line, which includes research into new types of chip design and different types of chip material such as gallium arsenide. Advanced designs of microelectronic chips as sensors, instruments and special processors

are also be part of this program. Moreover, the CAD/CAM technologies and the more advanced CIM (Computer Integrated Manufacturing) are important aspects of research and development required to remain competitive in the rapidly-moving microelectronics environment.

Testing and Inspection Services

These services are often required to assist manufacturers in getting their products into the international market place. Non-standard test equipment often cannot be afforded by industry. Such equipment as an example, should be directed towards the testing of systems in different environmental conditions and towards the testing of sensors. These testing and inspection services do not refer to the actual diagnostic testing of microchip performance, which is naturally part of the quality control aspect of the fabrication facility.

Education

Education programs must be re-assessed in the educational institutions and in industry. Within the next few years designers will be using different tools and techniques for designing large complex chips, and education institutions must train many specialists with microelectronics and software skills.

Computer Systems and Other Enabling Technologies

Important to LSI and VLSI chip manufacturing are software engineering, human-machine interfaces and knowledge-based systems. These technologies are the ingredients that will provide for the cheapest, most effective and most marketable systems of the future. Some of these initiatives are underway in Alberta and require coordination with the capability offered by a microelectronics chip fabrication facility.

Industrial Assistance

Programs in industrial assistance are required to assist small and medium sized companies in using chip design and fabrication facilities. Venture capital, funding assistance and meaningful tax incentive programs can provide leverage for small Alberta and Canadian companies to effectively enter world markets.

Relation Between Alberta Microelectronics Chip Fabrication Facility and the Proposed National Microelectronics Facility

A national microelectronics facility is being proposed to NSERC by a University Microelectronics Committee. D. Hill of the University of Calgary has represented Alberta on the national proposal and has also contributed to the Alberta proposal. The national proposal is consistent and complementary to this Alberta proposal. Some features of these proposals are outlined below.

Features

National Proposal

- driven by university needs
- emphasis on chip design
- provision for CAD stations at some 26 universities after 5 years
- provision for coordination of expensive software packages to complement software of the design workstations
- provision for new software development

Alberta Proposal

- driven by industrial needs
- CAD capability in-place at U. of A. and U. of C.

- 'major' research and development fabrication capability (laboratory line)
- up to three 'minor' centers dealing with process technologies and simulation capability
- research and development (laboratory) fabrication line
- industry access to chip design
- low volume chip manufacturing line to serve needs of industry
- provision for high volume chip manufacturing line depending upon market demand and security of microchip supplies.

Comparison of the national proposal with this proposal reveals that the national proposal is university driven and is directed primarily (at least initially) towards the design of microchips. In the Alberta proposal, industrial needs and applications of microchips is the central theme, with an emphasis on microchip fabrication. Some overlap occurs a) as a consequence of the design capability already in place at the universities in Alberta (note that the national proposal aims towards CAD stations at some 26 universities) and b) both proposals suggest research and development (laboratory line) fabrication facilities (the national proposal envisages one 'major' center and three 'minor' centers). Clearly, coordination is required between these two initiatives. The approach Alberta should take towards this coordination is as follows:

- 1) recognize the importance of chip design and simulation; encourage (but not contribute to financing) the design network of the national proposal
- 2) coordinate with other universities across the country (under the auspices of the National Microelectronics Facility) through the exchange and development of CAD expertise and software

- 3) Invest in the laboratory line as a research and development fabrication facility to serve both Alberta needs and national interests. National investment in the Alberta-based laboratory line should be encouraged. However, Alberta should be prepared to develop it alone if joint sponsoring cannot be negotiated
- 4) Invest in the low volume manufacturing line, not only as an industrial development strategy for Alberta, but for the nation. The general consequence of this approach would see Alberta
 - a) taking advantage of developments in chip design conducted across the country
 - b) providing technological advances in chip fabrication for use by universities and industries in Alberta and Canada and
 - c) placed in the enviable central position of providing open fabrication services for emerging industries in both Alberta and Canada.

In summary, the approach put forward here would cater to industrial development of Alberta with a responsible contribution to the Canadian microelectronics industry. Moreover, an appropriate component of research and development with national and international ramifications would occur in Alberta.

Implementation and Financial Forecasts

Details on implementation and facility costs are given by J. Robson in Appendix 2 (Implementation and Operations of an Alberta Microelectronic Chip Fabrication Facility).

The implementation time depends upon the scale of the facility. In addition, the availability of support teams, who have had experience in installing facilities, affects the implementation

schedule. One recent installation of an automated production line in the United States was conducted in nine months.

Facility costs are described in terms of the laboratory, low volume and high volume production lines. Costs can range widely. For example, over six years, capital and operating costs of a low complexity laboratory line are \$14.8 million. Alternately, over six years the capital and operating costs of combined high complexity laboratory, high complexity - low volume and high complexity - high volume production lines are \$146.8 million. To determine an initial level for facility activities, three factors are important:

1. the need for research and development
2. the need for industry access to open fabrication facilities
3. a reasonable expenditure budget.

These conditions can be met by development of medium complexity laboratory and low volume production lines. As illustrated by Robson in Appendix 2, the accumulated negative cash flow of the laboratory line (after six years) is \$15 million while the accumulated positive cash flow of the low volume production line is \$15.6 million. Thereafter, the combined accumulated cash flow is projected to be positive. Other combinations of lines offer different revenue - expenditure relationships. Benefits accrue in terms of:

1. research and development associated with the laboratory line
2. jobs and services connected with the low-volume production line, and associated chip design initiatives
3. attracting skilled manpower and high technology industries due to the facilities acting as a technological "nucleation center".

Management and Administrative Structures

An overall framework for all design and fabrication activity is proposed. This is desirable because efficiencies can be gained through coordination. For example, one mask making centre (part of the fabrication process) can be common to the proposed laboratory line and low volume manufacturing line. In general, compatibility between the laboratory line and manufacturing line assures efficiencies in terms of staff, equipment and technologies, and also eliminates the so-called second source problem.

From the organizational view point, components of the facility would include research and development, marketing and liaison, operations, and administration. The facility should be operated as a business, and even much of the research and development component can have a profit motive. Because of the need for the laboratory and the manufacturing line, together with the requirement for compatibility between the two lines, a reasonable framework would lie in the development of the two lines, with a specific arrangement for coordination. One way to provide coordination is through an industry-weighted Board of Directors with strong national and international awareness. It is recognized, however, that the precise framework and overall coordination will necessarily be dependent upon the nature of funding for the facility.

Roles of the Alberta Research Council are likely to be in the administration of government interests and in research connected to process technologies. Moreover, the Research Council by way of its Man/Computer/Machine Initiative in areas of software engineering and man-machine endeavours is likely to require the capabilities of the microchip fabrication facilities.

AMC provides a mechanism through which university access to the fabrication facility is most appropriate, and vice-versa, a way for industries to access CAD facilities in the universities. Moreover, with attempts to develop (as much as possible) profit-oriented

research and development, AMC could provide a direct link to university talent in support of industry-developed contracts.

As a summary of the broad operational characteristics of the facility, the following table shows how various components of the organization (noted above), including financing, may be provided by the three sectors.

Operational Characteristics of the Fabrication Facilities

Sector	Function
Industrial	- major buyer of microchips - operation of low volume and high volume production lines
(Financing and Operations)	- financing - marketing
Universities and Technical Institutes	- home for laboratory line and associated research and development - central design locations - research input to designs - provision for development of design, simulation and sensor technologies
(Research and Development)	- coordination with national microelectronics program - new technology research
Government	- provision for connecting programs (education, testing and inspection, research and industrial assistance, new technologies)
(Financing and Coordination)	- financing - overall coordination of industrial, university and government interests

Some of the major Alberta organizations now contributing to microelectronics and software technologies are listed below, showing possible contributions to the fabrication facility. These anticipated contributions are only presented as guidelines to give an indication of resources available, and are either based upon ongoing activities in the organizations or what might be reasonably expected as contributions to the fabrication facility. Contributions in the following table are estimated to be at least \$5 million.

Organization (Agencies)	Possible Contributions
Industry (as a group)	- Technological and business management know-know - out-of-province marketing
Alberta Microelectronics Center	- in-province marketing - industrial training - technological link between industrial needs and university-based research
University of Alberta	- CAD - design, simulation and sensor programs - manpower training
University of Calgary	- CAD - design and simulation programs - manpower training
Alberta Research Council	- contributions <u>in-kind</u> (land, buildings, etc.) - provision for connecting programs - overall coordination of industrial, university and government interests

Funding

The low volume manufacturing line is to be developed to provide an appropriate return on investment, as well as to provide an open facility for use by industries in need of custom microelectronic chips. In this regard, it is appropriate to primarily consider venture capital funding and direct industrial funding for this low volume manufacturing line. Some government support or incentives would also be necessary to ensure access to this line by small industries. The low volume manufacturing line has the capability for positive accumulated cash flows in the short term (several years). The complimentary laboratory line, which is intended to provide a training ground as well as to develop new process technologies, is a long term investment. This line would more appropriately be funded by Provincial and Federal governments. About 75% of total costs would be directed towards the low volume manufacturing line, with about 25% directed towards the laboratory line.

APPENDIX 1

MICROELECTRONICS STEERING COMMITTEE

B.L. Barge (Chairman)	Alberta Research Council
M.R. Johnson	Alberta Research Council
P.C. Williams	Alberta Research Council
W.W. Armstrong	Comp. Sci., University of Alberta
C.R. James	Elec. Eng., University of Alberta
D.R. Hill	Comp. Sci., University of Calgary
G. Hope	Elec. Eng., University of Calgary
N.L. Arrison	Global Thermoelectric Power Systems
P.E. Jackson	Northern Telecom
J. Kendall	Noval Technologies Inc.
J.R. Robson	Alberta Microelectronic Centre
E. Roesler	Alberta Government Telephones

APPENDIX 2

ALBERTA, INFORMATION TECHNOLOGY AND THE PROPOSED
NATIONAL MICROELECTRONICS FACILITY

by

D.R. Hill, G. Hope, J. Kendall

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SUMMARY

This paper outlines the background to current national and provincial research and development initiatives in VLSI design and fabrication. After identifying the four enabling technologies underlying the Information Revolution, and briefly explaining the nature of VLSI, the paper goes to show the close parallels between the previous Industrial Revolution and the current Information Revolution. It is noted that we have just reached the same critical development stage of 'inventing the machine to make machines'. The importance of VLSI and related topics to the survival of modern nations is spelled out. The current major bottlenecks in developing this important enabling technology (VLSI) are identified as lying in design manpower, design software, and mask making. In Canada the situation is particularly acute. It is noted that the current recession has, paradoxically, opened a 'window' in time, during which Canada, and particularly Alberta, can take steps to participate fully in the benefits to be expected from establishing high tech industries based on the Information Revolution, and in particular on VLSI and the related software enabling technologies. Some initiatives have already been taken. What more needs to be done is spelled out within the international, national, and Albertan contexts.

ALBERTA. INFORMATION TECHNOLOGY AND THE PROPOSED NATIONAL MICROELECTRONICS FACILITY

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February 20th. 1983

INTRODUCTION

The Science Council of Canada, concerned with advising the Federal Government of Canada on policy, has described the situation facing Canada today as 'the greatest development challenge of several decades'. It states that the face of industry is changing in a way not seen since the ferment of the industrial revolution. The SCC documents the urgent need for planning in their recent report: *Planning now for an information society: tomorrow is too late* (1982). Because of the importance of Information Technology (IT), both as the most rapidly growing market place in world trade, and as the dominant influence on competitiveness in all other sectors of national economic and social performance, developed countries are urgently re-allocating resources, and planning massive research and development programs. All this is happening despite the most serious recession since the 1930's. It is partly early recognition of these trends that has placed Japan in its currently dominant competitive position in world trade. Japan plans to maintain or increase that lead with its Ministry of International Trade and Industry investing at least \$500M into its nationalised computer effort over the next five years; and with the individual companies involved matching the government funds many times over, bringing the total according to some observers to perhaps \$4B (Posa, 1981).

In Britain, where considerable government money has already been spent to encourage the development and application of the new technology, on top of that spent by successful companies, the Alvey committee, in its report: *A programme for advanced information technology* (1982), recommends that the government should fund 75% of a \$700M five year research programme in what it calls the four 'enabling technologies'. These are:

- software engineering
- very large scale integration (VLSI)
- man-machine interfaces; and
- knowledge-based systems.

These topics are central to what has been termed 'Fifth Generation Computer Systems'. Such systems are confidently expected to give considerable competitive edge in world markets to their successful producers. Application of such systems will affect the competitiveness and effectiveness of all other institutions in society, and will also create new kinds of application. In Japan, there is also emphasis on desirable social objectives. Certainly, more easily used, cheaper, and more effective systems can (for example) affect the quality of administration in local, provincial and national government, or provide

services that are currently uneconomic. However, there is a negative side. First there is the potential damage to the quality and privacy of life, especially in the work-place, that has already led, in some countries, to the appointment of 'data shop stewards' to monitor and avoid damaging consequences of this kind. More serious are the socio-economic implications of failure to meet the challenge. Such a failure would lead to increasing dependence on non-renewable resources. This would occur as competition in other markets drove us out, as new products took over, and as the cost of administering society escalated in the face of dependence on imported technology and systems.

This is why France has set a national goal of becoming the first nation to pioneer the new kind of society, and is investing vast sums into the relevant areas of research and development. We are at a cross-roads. It may be that we cannot afford to keep up, or that we should make a conscious choice to slide into pastoral, dependent poverty. But whatever we do, we must do knowing where it will lead us, and we must be prepared to accept all the consequences. The message in this background paper, however, is that we can and must succeed in rising to the challenge. There is particular emphasis on the effort needed to develop a national capability in VLSI design, fabrication, and production.

WHAT IS VLSI ?

In 1946, the transistor was born as a result of basic research at Bell Laboratories in the US. Rapid development, first of the germanium transistor, then of the silicon transistor led to many important industrial products that served industry and the military, as well as consumers. The transistor radio was a sensation when it first came out, but other products were equally sensational. Amongst these were transistor based computers that, because of the relatively low power and high reliability of transistors compared to older vacuum tubes, made computer power much more 'usable', and paved the way for increased power.

Transistors work because the electrical properties of materials like germanium and silicon vary according to small amounts of deliberately added impurities ('dopants'). Different compositions, in contact, set up fields allowing large main currents to be affected by comparatively small control currents, using relatively low power. Originally, transistors were made on small chips of silicon, one at a time, with a three-dimensional structure. Soon many transistors could be fabricated on a chip by a process analogous to printing, in the sense that the patterns of impurity, connection, and the like could be laid down in what amount to two-dimensional patterns (all connections one side, with the third dimension of only microscopic extent). Fabrication progressed through integrated circuits, and large scale integration (LSI) to VLSI. Most recently, experiments have started that promise to use the full extent of the third dimension to build up successive layers of patterns to give a full three dimensional array of transistors and related components. Even with two dimensional arrays of components, the patterns are so fine (measured in millionths of a meter or less) that tens or even hundreds of thousands of transistors and related components, with their associated connections, can be placed on a chip less than the size of a thumb nail. This is VLSI, and it has made computers and similar 'intelligent' devices so small and so cheap (since mass production is possible and the mass market exists for low-cost functional intelligence) that it is cost effective to use information processing

power in quite inexpensive goods -- cars, washing-machines, watches, and even toys. At the same time whole new vistas of information processing for the benefit or amusement of society have opened up. This is the information revolution. If the same progress in automobile technology had occurred, as has occurred in information processing over the last 20 years, it would now be possible to buy a Rolls-Royce for \$10 and drive it round the world on five litres of gasoline.

VLSI is not just 'more and cheaper': It is a statement about possible system complexity. To quote Carver Mead, one of the leading innovators in making VLSI technology available:

VLSI defines a technology capable of creating systems so complicated that coping with raw complexity overwhelms all other difficulties.

(Mead, 1981). Mead takes another analogy for progress in VLSI from Seitz (1979), who was looking at things from the designer's rather than the user's point of view. If designing chips in the mid 60's can be thought of as designing the street layout of a small town, then designing in the 80's is comparable to designing a street network covering the entire North American continent.

One further point must be made, before leaving the topic of 'What is VLSI'. It relates directly to the problems of managing the complexity noted above. The greatest bottleneck in exploiting the power of VLSI techniques lies in design. Increasingly the skills needed to manage the complexity of VLSI design are being recognised as those used for some time in the design of large software systems (the program suites, or recipes, needed to make computers perform the myriads of tasks they cope with). The current design tools include logic simulators, graphics packages, and (most importantly) so-called 'silicon compilers'. Compilers are one of many basic inventions to manage complexity of programming invented by computer scientists. Compilers allow the user to write at a higher level of abstraction or conceptualisation more appropriate to the problems being solved, instead of requiring the user to deal with incomprehensible minutiae. FORTRAN was one of the earliest compilers. Current silicon compilers, insofar as they exist at all, are more akin to assemblers. Graphics layout software is at an equally primitive stage. Expansion and innovation in these 'software' areas is crucial to progress in VLSI and survival in the Information Revolution. This theme is developed in the introduction to the next section.

THE IMPORTANCE OF VLSI: THE INFORMATION REVOLUTION

Introduction

The information revolution is comparable in impact to the earlier industrial revolution. There are also parallels in its development, execution, and consequences. The 1957 edition of Encyclopaedia Britannica has this to say of the Industrial Revolution, by way of introduction:

When we say that a society has passed through the industrial revolution we have in mind a definite picture of its life and power. We are thinking of a society that makes great use of machinery and conducts its operations in industry and commerce on a large scale. The creation of any such society must be in some respects a gradual development. Certain features of our modern economic life can be traced back to the days when Columbus and the great sailors of his time put Europe in touch with the new world and the far East; others to the earlier history of Europe when classical Greece, and the Roman empire in turn exploited the wealth of the mediterranean basin. There was large capital invested in industry as well as in commerce before the 18th. century,

and even so modern a phenomenon as mass production was not altogether unknown before the industrial revolution. No people and no age could pass directly from a primitive and simple economy to a life so complicated as that of modern Britain or modern Germany. Some critics, surveying these earlier tendencies, doubt whether the term industrial revolution is appropriate, arguing that revolution implies sudden and catastrophic change. But a closer examination shows that the great inventions which distinguished the 18th. and 19th. centuries played so decisive a part in creating the new kind of society that the term industrial revolution, invented by a Frenchman, and made familiar by Arnold Toynbee (1852-1883), is not too violent a description of the changes they produced.

The section goes on to note that, in engineering (which is central to the industrial revolution), probably the most important of Watt's discoveries was the use of machines for making machines. It goes on:

In earlier ages, the chief obstacle to industrial development was the difficulty of land transport. In Germany and America, this difficulty was resolved by the railways. In England, on the other hand, where the sea was nowhere very far distant, an industrial revolution was possible without the railways, because canals and roads could give access to the ports. It was mechanical engineering that received the greatest stimulus from the railways. Therefore, when the world wanted railways and docks, England was ready with the plant, the experience, the capital, and the skill. Hence it was to English capital and English labour that the world turned for this task. But there was a difference between the early days of the revolution, when England sold piece goods all over the world, and the later days, when it sold railways; for the railways it sold sometimes helped to turn agricultural into industrial societies, and it was certain that when this change had taken place, England's preponderant share in the trade of the world would decline. When the 20th. century opened, England had powerful industrial rivals both in and out of Europe, many of them with far greater natural resources to exploit, and one of them, the United States, with a far greater supply of capital per worker.

The US subsequently took over as world leader because it had learned the new technology, and was in a position to exploit it. It is important to note the parallel with the currently touted 'Information Revolution'. The actors have assumed new roles but we have a similar developmental picture for information-based machines now, as they replace human brain power, and permit hitherto unthought of or previously impossible developments, as for the energy-based machines of the last revolution which replaced human muscle-power, and permitted similar innovation in activities requiring muscles.

VLSI permits, in principle, information processing of arbitrary character and complexity. The information processing made possible is the very tool needed to deal with the complexity, and make practical and affordable what is possible in principle. We are in the process of discovering the new 'machine to make machines'. There are some crucial differences, however. The machines of the Industrial Revolution were driven by energy, and made themselves under the direct guidance of skilled humans, who learned by experience and direct feedback how to do the jobs (a poor lathe could make a better lathe in this way). Information processing machines are driven by information (power requirements are not at issue, so no invention is required there), and the human skills involved are at a higher level of abstraction and complexity. They are programming skills. In just the other three areas noted in the Alvey report, indeed, the distinction between software (programs to guide information processing machines in their work), firmware (software more or less permanently written into special memory), and hardware (physical parts of information processing machines) is becoming increasingly devoid of meaning for other

reasons as well. A program may be represented as a printed listing on a page, or as a printed design on a VLSI chip (Intel actually offer a chip form of a complete operating system of some complexity — CP/M on the 81501 chip). Equally, the logical characteristics of a machine — what instructions it will obey — can often be changed to create a new machine with different characteristics by altering the control store part of the hardware, which amounts to a program change.

The boundary between hardware design and software design (building the machine — usually in VLSI, and figuring out how to make it do different things) has become extremely blurred. It is hard to contemplate doing well at one without understanding the other, especially in the newer applications areas. What used to be done by so-called 'random logic' (custom logic made of many standard varieties of integrated circuit and LSI chips) is now done, and will increasingly be done in the future, by custom LSI and VLSI chips. Many 'systems' now fit on a single chip. Systems design involves intimate interaction between hardware and software requirements. A single chip can do what would have required a whole rack of equipment (with power to match) only two years ago. Furthermore, much of the associated software is usually incorporated into the silicon in one form or another, whilst what is left is highly dependent on the chips to an extent that has not been true before. The continuing trend towards ever more complex custom chips, and the concept of 'total systems integration' that would put a complete modern telephone switching system on a relatively small area of silicon, leads to considerable reduction in costly wiring, connectors, and size. Not only is the systems phenomenon likely to increase, but the importance of custom chips, and of solving the design problem at reasonable cost, will increase. This all means that it is no longer possible to separate the design of the chips from the design of the system, or the design of the software to make the system work — especially since software serves to design the hardware in the first place. The best and cheapest systems will be produced by those able to control and match all three components in the final product, whether it be a Telidon terminal, or an intelligent toaster.

The crucial point to make is that software skills are part and parcel of the design and use of VLSI technology. In talking of fifth generation systems and their benefits, it must be noted that the four enabling technologies are actually highly interdependent. Each area draws for success on the other three; which puts this essential industrial development unequivocally at the leading edge of current research for its source of innovation and progress. At the same time, its imperative is the health of the entire nation: jobs, services, balance of trade, security, and future.

The International Context

Industry and university leaders in information technology throughout the developed world are urgently planning to meet their various national needs for highly skilled manpower in the areas crucial to survival under the information revolution by programs for retraining, and by massive new research programs. Some of these have already been noted. VLSI programs feature prominently in all this activity. Mead (1981) has stated that throughout the evolution of courses and research projects in VLSI, there has been a continual difficulty in gaining access to chip fabrication facilities (even in the US). Noting the generosity of individual companies in making facilities available, he states:

While these favours were crucial to getting university programs going, they obviously cannot be the basis for supplying a multitude of emerging small system firms, nor can

they support the expanding group of participating universities. What is needed is an openly available service facility which will, for a fee, accept pattern files in standard format (which we have already worked out) and 'print' them on silicon wafers using a standard fabrication process.

In another paper (Mead and Lewicki, 1982) such a service facility, or 'silicon foundry' is likened to the forges that serviced the earlier machine industry. The authors, certainly with the Industrial revolution in mind, note that ordinary capital is consumption foregone to create productive capacity which must be wrenched free to feed the sources of creative intellect. They also describe intellectual capital as 'students going to school. Instead of getting a job', and it is noteworthy that the rise of education in England was based on the need to create the necessary skilled workforce for the Industrial revolution. In Germany it was Bismark's response to their inability to compete with England. Intellectual capital (people imbued with knowledge and ideas) is essential as a basis for the innovation needed to employ ordinary capital to the benefit of society. (The consumer has often benefited as much as the industrialist from the resulting increase in production). In writing about the success of California's 'Silicon Valley' (the 'largest floating technology crap game in the world' and birthplace of: the integrated circuit; the microprocessor and microcomputer; the personal computer and first retail computer store; and most recently genetic engineering), McKenna (1982) notes that 44% of all productivity gains stem from innovation and new knowledge. This compares to 16% each for economies of scale, and for new plant and equipment, and of 12% from better resource allocation.

McKenna goes on to note that the gains are most evident where computers, telecommunications, robotics, and microcomputers are being put to work. These are visible aspects of the power that now derives from VLSI. Information Technology is indeed IT (quite literally!).

So important is the provision of proper facilities for teaching and research to the production of ideas and highly skilled manpower that about 10 US universities have been given money to set up their own chip production facilities (chip foundries). Thus North Carolina has been given US\$28M, and MIT US\$16M. Part of this difference in funding lies in the fact that the former facility will not only have a frozen (or pilot) line, but also a development line, with which those interested in the physics and engineering of chip production can carry out investigations into better chip fabrication methods. The pilot lines serve as a training ground for chip designers, and as an experimental facility for innovation in systems design based on faculty research. However, at present, even at Stanford, students must work with chip projects put up as designs by their predecessors, the turn-around is so slow. This is hardly conducive to the highest standards of education.

The University of Oslo, in Norway, is constrained to sending chips to the US for fabrication, at present, as is the University of Edinburgh, in Scotland, which offers VLSI design to its undergraduate students. The latest news from Edinburgh is of an award worth \$5M for chip research.

This view suggests that, given time, the situation may improve, with additional capacity being made available, and an international network developing. However, as might be expected in this economically vital area, the flow of information and technology is starting to be restricted. Following a series of moves by the US to counter the growing Japanese threat to their world trade in the goods and services associated with Information Technology, including

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trade restrictions and trade secret prosecutions, even US universities are becoming secretive about their chip production techniques and software. Economic realities are coming to the fore, and the US is no longer prepared to supply the competition (even friendly Canadian competition it seems) with free information on what is new and worthwhile in these crucial areas (e.g. Strauss 1982). Japan in the meantime has quite baldly stated its aim to dominate the world with its fifth generation systems in the comparatively near future, based on making them exceedingly powerful and very easy to use. At the same time INMOS in the UK are claiming to be able to stave off the 'threat' from Japan, whilst importing licensed chip technology from the US. No country can afford to be dominated by any foreign power to the extent that is possible if the country lacks domestic capability in VLSI, beyond a few licensed (and inevitably technologically obsolescent) frozen foundries, tied to individual companies needs. Nor does it seem wise any longer to hope for purchased services abroad (even ignoring the balance of trade problem). Neither case provides the basis for being at the leading edge of technology, nor for bringing in new products to exploit the fabrication methods that are just about to become standard. Neither case provides a basis for keeping the best people in the home country. People will go where the challenges and opportunities lie. This can be a benefit if they ultimately return, bringing new skills with them, but it is a double loss if they stay away because of lack of worthwhile facilities at home.

THE CANADIAN CONTEXT

A major national effort in VLSI is essential as a component of Canada's involvement in the Information Revolution. Success in all the areas involved is vitally important to Canada's economic recovery and future health. Success will promote the growth of new industries able to compete successfully in world markets, thereby creating new jobs at all skill levels, and reducing Canada's dependence on imported information-based systems. This will affect national security as well as the balance of trade.

The industrial activity concerned is one of 'high value added' goods and services. Cheap raw materials, in small quantities, are worth a great deal when sold, after processing. Such goods and services are in huge and increasing demand. Most economic activities depend on them, from manufacturing and control, through data-base and information access systems, to government activity (both military and civil). Innovation in both software and hardware, i.e. techniques and equipment, is vital to continued competitiveness for any organisation using such services. The goods and services involved are not just conventional data processing services. They comprise new applications and techniques together with components that increasingly distribute information handling power into more and more of the products on which society depends. Industrial production increasingly depends on intelligent controllers and robots. Oil discovery and production increasingly depends on new analysing tools, graphical devices, and field installed processors for well management and pipeline control. Transducers of increasing sophistication are needed for the same activity, many only possible through special VLSI fabrication. The consumer goods that sell best increasingly incorporate built-in micro-electronics to make them energy efficient, cheaper, reliable, and more convenient to use. Lucrative new markets are developing on the basis that things can be done now that were impossible or prohibitively expensive, prior to the Information Revolution.

Four years ago, it seemed reasonable for a country to proceed on the basis of buying in the chips needed for system design and manufacture. It is now clear that this is no longer true. However, on this basis, a number of microelectronics centres have been set up around Canada, with Federal and/or Provincial funding. Co-operation between industry and universities is being strongly encouraged, especially in the areas noted above. New courses have been set up that offer combinations of computer science and engineering.

The main emphasis of these measures has, so far, been to promote new applications for micro-electronics, in keeping with the buy-in philosophy. The question posed was 'what kinds of new uses, in improving productivity and creating new products, can one think of for chips'. Along with this has gone a mandate to educate small and medium sized industries that might otherwise have lacked the resources to investigate such matters. One particular area of success for Canada has been that of computer communications — for example, Telidon, the graphical system tool for accessing public data banks, comprises software built on a physical system made up of microchips.

Now that it is seen that the situation has changed, a new direction and urgency has become apparent. There are several reasons for this. They are all connected with the basic importance of control over the supply of chips, and the ability to have secure supplies, and to be able to design and produce them ahead of the competition. They are also connected with the fact that many systems now fit on a single chip, with all the ramifications noted above. The communications area is one of the big success areas for Canada as far as system design to date is concerned, and it is instructive to note that Northern Telecommunications have invested considerable resources into chip fabrication facilities of their own. Even so, they are currently dependent on the Japanese competition for the very highest speed devices. They also suffer from the general shortage of design skills and software for custom VLSI. What may happen, if the designer shortage is not alleviated soon, is anybody's guess. In this we must not ignore the requirements for other companies with similar capacity, let alone the spate of existing and new companies that have no design teams at present, and cannot afford their own fabrication plants.

Part of the answer is for universities to provide the training required to produce highly skilled manpower in the relevant hardware and software areas. At present, Northern Telecom has generously and far-sightedly made some of its production facilities available, on a restricted basis, for university training. As an immediate stop-gap measure, this is invaluable, and may prove to have saved the Canadian capability in the area by the example set, and consciousness raised, as much as by the facility provided. However, the total volume that can be handled within budget restrictions is likely to prove inadequate in the long run and it is planned for student projects, to educate designers, rather than as a faculty or industrial research facility. Furthermore, it cannot serve as a development line, for frontier research in fabrication technology, since it is frozen, and subject to commercial security. Since 'yield' is a critical parameter, the line cannot serve as a test-bed for better ways of making chips. Even as it stands, there is a turnaround problem and a lack of detailed information on process parameters needed for design. At present, it takes up to a year between submitting a design, and getting it back. This is because there are currently two submission dates a year. If a design just misses one, it could be nearly six months before the next date, and a further six months to get it back. If it could be guaranteed that submitted designs would not fail during the fabrication, due to some error or misunderstanding, during the

fabrication process. It would be possible to reduce the time involved by putting batches on priority, but this requires a gradual building of confidence and expertise. It also requires a possibly unattainable degree of perfection in the logistics of managing student projects and liaising with the organisation involved (the National VLSI Implementation Centre or VLSIIC). Northern Telecom have, in fact, promised to speed the turnaround and make some process parameters available, further indicating their goodwill and desire to help, but it is illustrative of the difficulties. Other companies (e.g. MITEL) have also offered to help with other kinds of processes. Nevertheless, one is mindful of Mead's remarks.

THE NATIONAL PROPOSAL

Against this background, a group of around 50 experts from Canadian Universities and industries, has generated a proposal to the federal government to establish a Canadian silicon foundry to serve the national needs outlined above. Originally, a dual-line facility similar to that at the University of North Carolina was proposed to provide a pilot line serving the needs of education and faculty research in VLSI design, with a development line to serve the fabrication researchers. A unique facility was proposed, to serve all universities, to concentrate resources, and build the kind of world-class centre that would attract staff of the highest quality (some being Canadians now working in the US). Industry collaboration and participation was seen as very important, except that the original proposal did not intend to serve industry as a foundry. This omission was seen by some as a deficiency.

The original proposal, estimated to cost around \$65M over the first five years, and about \$10M a year thereafter in operating costs and perhaps \$6M a year in capital renewal, has been evolving. The final form of the proposal, as submitted to the government, takes the following form. To address the design problem, a *design engine* is proposed. This initiative would place high-powered CAD/CAM stations at around 26 universities by the end of five years, together with testing facilities. Some universities would have more than one such station. The VLSIIC at Queen's University would be strengthened by providing a VAX 11/780 and additional staff. The centre would co-ordinate the submission of designs to companies volunteering access to their fabrication lines, and would act as a clearing house for software. Large expensive packages would be acquired by the VLSIIC to complement the basic design software supplied with the design stations, and would be distributed over public data facilities to the participants. In addition, a further comparable sum of money would be made available to develop new software within the system. This too would be distributed and maintained by Queen's VLSIIC. The total cost is budgetted at \$17M over 5 years, including the provision of funds to extend the industrial fabrication services.

To cover the original 'development line' proposal, the current submission proposes a distributed approach, to capitalise on existing expertise. However, one centre would be the major centre, and up to three 'minor' centres would also be supported, no more. The major centre would have the capability of taking a chip through all stages of creation. It is proposed that this aspect of the national initiative would be partly funded by industry, and a joint management board would be set up with a program committee and director under it to co-ordinate research plans at different centres to avoid unnecessary duplication of research effort. Links would also be made with the design engine. Equipment for both initiatives would be owned by the organisation, and could

be recalled and transferred as needed. The fabrication initiative would consume a budget of around \$60M over five years.

No production facility, or service to small industry is envisaged.

The prospects for obtaining funding for the design engine seem good. The future of the other part of the proposal is less clear, but both are clearly necessary, and even together, they address but part of the total problem.

THE ALBERTA CONTEXT

Alberta and the NMF

Alberta has pursued a policy of diversification and expansion, thus planning for the future, and avoiding imprudent dependence on resource based industries and agriculture. There are difficulties in pursuing this policy. Apart from the need to husband scarce financial reserves wisely and cope with a serious recession, new industries require skills, and may run into problems of competition, access to markets, and potential for growth.

No matter where the National Microelectronics Facility (NMF) for chip fabrication is located, there will undoubtedly be a serious problem recruiting the skilled persons needed to run the line successfully. However, some successful industrial lines have been set up in Canada, and start-up skills and technology can still be obtained (though for how long ...). Part of the reason for creating such a facility is to be able to grow our own expertise to solve just this kind of problem.

As far as the problems of competition, access to markets, and potential for growth are concerned, proposals to create facilities are:

- (a) intended to allow Canadian efforts in the new information-based industries to be more competitive;
- (b) addressing an area where the potential for growth is more of a certainty than a potential;
- (c) aimed at an industry for which access to markets, especially transportation, largely ceases to be a problem, whether one is discussing microchips, or software. Even complete systems are normally air-freighted since, with modern technology, they are small and valuable.

Point (c) is of especial relevance to Alberta.

On the subject of husbanding scarce resources wisely, one can only point out that, in the current situation, making the investment necessary to support any initiative in VLSI can only be regarded as a unique, incredibly valuable opportunity to get in on the ground floor of a whole new range of modern, high-technology industries. As Silicon Valley in California, and to a lesser extent the Silicon Valley North (the Ottawa valley), have shown, high technology investment has a snowball effect. The NMF will undoubtedly prove to be an entrepreneurial nucleation centre of the first magnitude, creating new industries, wealth, and jobs in the area, as well as training the manpower needed to fuel the expansion. The NMF promises to be a very potent seed.

Many of the above points are general in nature and could be raised by responsible people in any part of Canada where such an activity could be contemplated at all. Indeed, it is to be fervently hoped that good sense will prevail, and the NMF will be set up, much as planned, possibly even extended as suggested below. However, there are two important problems. First, it

is not clear that the Federal government will be able to afford the full cost, despite optimistic predictions, at least not immediately. Yet speed is vital, especially given the rapidly increasing difficulty of acquiring the information and skills needed for start-up, not to mention the need to establish a market position for Canadian products in this area. Thus there is a budgeting problem. Secondly, there is the question, peculiar to Alberta, as to why it would be good for the country, and for Alberta in particular, for the NMF to be located in Alberta.

On the budgeting side, we see Alberta provided with a unique opportunity to make a key investment that will be good for Canada, good for Alberta, and should repay itself many times over. Moreover, it is an investment that should help to guarantee that this important project goes ahead in the face of federal fiscal constraint. With the right kind of initiative from Alberta, in terms of sharing the cost and providing an appropriate future-growth environment (such as a research park, or university reserve), the federal government may find itself presented with a sufficiently reduced commitment that it is able to proceed with dispatch. Nevertheless, whether the facility is located in Alberta or not, the provincial government should seriously consider a generous contribution if only out of the enlightened self-interested point of view that what is good for Canada is almost certainly good for Alberta.

From a National point of view, there is some merit in locating the facility in Alberta. First, it avoids a total concentration of skills in the East, and shows a willingness to develop the potential of Western Canada. Secondly, it places the NMF on the traditional North-South line of communication with the many West-coast facilities in the states -- likely of help in recruiting, attracting visitors, obtaining raw materials for chip production, and possibly mitigating the worst effects of any restrictions on knowledge exchange that may arise. Alberta has a more attractive winter climate than Vancouver, and a more attractive summer climate than Ontario and Quebec. It offers the kind of challenging leisure pursuits that attract highly motivated and technically skilled people, and has great potential for future growth.

An Alberta Proposal

Regardless of how the National question is settled, it makes excellent sense to consider major Albertan initiatives in VLSI. The rewards are great, the time exceedingly opportune, and a provincial facility, quite apart from fuelling real diversification and growth in the province, could address areas untouched even by the full national proposals. A three-tier integrated facility could be built, in conjunction with industry brought into Alberta and would immediately create overwhelming drive for further new industry in high growth areas. Suitable contacts already exist. However, if the province delays, the recession will end, and the opportunity will be lost for good.

The details of a proposal for Alberta to enter the Information Technology stakes form the subject of separate documents. Here it is only intended to state a few broad ideas, independent of the final outcome of the full provincial steering committee deliberations. However, a silicon foundry would be an important component of any major proposal.

Two possible scenarios are somewhat similar to the two proposals, original and current, that are being considered by the national steering committee. It is the third alternative, however, that is probably the most attractive. It involves the immediate creation of a profitable high tech venture, entirely funded by industry, according to business plans already drawn up and supported by

potential partners with the required expertise.

The Alberta government and the Alberta Research Council have favoured joint ventures as a means of promoting research and development to encourage the expansion or creation of industrial activity in the province (see, for example, appendix A2). In the case of the proposed facility, which is very expensive, a number of immediate problems may be alleviated if the facility, rather than being a cut-down version of the original NMF proposal, were an expanded version: a three tier proposal that went in phases over several years (though not too long), with the aim of providing a development line (for fabrication research), a pilot line (for design education and systems research), and a production line. The production line would provide a custom VLSI service to all comers, and would also develop VLSI macrocircuit techniques at the leading edge of the technology based on in-house expertise acquired in the set-up. The pilot line would aim to provide for the research needs of industries (especially small, new, innovative industries) as well as universities, and would be compatible with the production facility. Designs produced as a result of research, which had commercial potential, could be moved to the production facility without costly redesign involved in moving to a new process. Possibly some kind of sliding scale fee would be applied for industrial users. If the demand were heavy, but it would be subsidised in keeping with Alberta's joint R & D venture philosophy. The production line would be expected to become profitable within a reasonable period and would very likely be the first component to come on stream. As noted, this third tier would be industry financed. However, it could share a building with the provincial R & D facilities, perhaps owning it and renting space to the province, or perhaps renting space from the province. The benefits would be considerable. A centre, unique in Canada, would have been created. Not only would its scale, quality, and comprehensiveness be very attractive to building its strength because high quality staff would wish to work there, but it would form an entrepreneurial nucleation centre of the first magnitude for the province. Furthermore, it would be in a very strong position to compete for federal funds of various sorts, to the extent that they became available, without being dependent on them. There are several other advantages. No one participant in this world class facility would carry too much of the cost. Even the cost of the production facility would be shared, and the government would avoid the necessity of taking an equity position in a commercial venture. The company would also be spared the application of government constraints in dealing with their problems of running a business. Nevertheless, the value of having excellent R & D facilities heavily subsidised by government immediately adjacent would be incalculable. The synergistic effect would be part of the attraction to user and service companies.

The attractions of the production facility to participating companies would be varied. First it is addressing a market that is estimated to reach \$95B dollars by 1995. With only a tiny percentage of the world market, it is realistic to project total sales in excess of \$500M by 1990. The facility could act as a secure second source for a series of companies who would value access to new design skills provided by cross-licensing agreements. Even Northern Telecom may be interested. Certainly a number of companies inside and outside Canada have shown interest. For this the quality, price and delivery would have to be right, but that is a *sine qua non* anyway. Secondly, companies may be glad to have someone else manufacture their tail-end runs, which could be a valuable source of cash flow and profit in the start-up phase. Most importantly though is the provision of state-of-the-art custom VLSI design and

fabrication facilities, that begin to meet the needs expressed in the earlier part of this document, and allow Canada to take advantage of what is a unique window in time (created, paradoxically, by the recession) to catch up with and exploit the current Information Technology revolution, and set up world class semiconductor systems and software facilities in Alberta.

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Need for the Alberta Microelectronics Facility

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NEED FOR THE ALBERTA MICROELECTRONICS FACILITY

1. Objectives

Major reasons for establishing the Alberta Microelectronics Facility in the province are to:

- i) provide our industry and educational institutions with a microchip fabrication service;
- ii) provide a major initiative in developing high technology industry. The Facility would act as a catalyst by attracting high technology enterprises and highly skilled professional workers to Alberta;
- iii) initiate an extensive program to meet the industrial, research and educational needs of the province including a significant sensor technology program which would have a unique international role.

2. Emerging Strategy

For the Government of Alberta to now establish the Alberta Microelectronics Facility is a logical next step in fulfilling Premier Lougheed's often stated goal of developing a strong high technology industry as part of the policy of the Government of Alberta to diversify the economy. This step will assist in exploiting the value added potential of this province's human and natural resources. Already the Provincial Government has made a considerable investment in the microelectronics field and an overall strategy appears to be emerging to build a fledgeling, dynamic electronics industry. The recent locating of the Bell Northern West Research Laboratories in Edmonton and the Northern Telecom Switching Plant in Calgary have been major new electronics industry developments in

Alberta. The presence of AGT in the province gives considerable strength to the electronics infrastructure. Along with encouraging industrial growth, the Government has provided considerable assistance to the University of Alberta and the University of Calgary to strengthen their departments of computing science and electrical engineering. With this assistance and their own resources, the universities have developed new programs such as computer engineering, made major computer acquisitions through, in part, the funding of the 1980's Advanced Education Endowment Fund, and made important faculty appointments in the microelectronics area. These undertakings have strengthened our university departments to the degree that they can make a very significant contribution in the building of the microelectronics field in the province. Another important step in the evolving microelectronics strategy is the new direction taken by the Alberta Research Council to become heavily involved in stimulating high technology growth in the province. A further component in the strategy has been realized through the recent creation of the Alberta Microelectronics Development and Applications Center which acts as an interface between industry and the universities. The founding this past August of the Electronics Industries Association of Alberta through the assistance of the Department of Economic Development of the Government of Alberta was another major advance in organizing the overall activity of the microelectronics field in the province and an essential link in the unfolding strategy. This association has a membership in excess of 100 and a potential membership of 175 or more companies. The latest development in the overall plan is the acquisition by the University of Alberta, through the assistance of 1980 Advanced Education Endowment Fund, of a sophisticated state of the art CAD/CAM (Computer Aided Design and Manufacturing) Facility. Such a

facility, once appropriately manned and equipped with software, provides the province with the capability of designing complex VLSI chips. The next logical step in this sequence is for the province to acquire the capability to fabricate, and test VLSI chips.

The need for a fabrication capability is not just confined to Alberta but is, also, a national need. The recent report of the Science Council of Canada called "Planning Now for an Information Society - Tomorrow is too late", recommended "that industry and government collaborate to develop and maintain a custom silicon-chip design and manufacturing capability". This past year, the VLSI Implementation Group was founded as an informal organization of Canadian universities with one of its prime purposes being the establishment of a "National Microelectronics Facility" with features similar in many respects to those proposed in this submission. Although the goal of this group is to realize one such facility in Canada, a very strong case exists to have more than one. Certainly, having more than one source of microchips is important in making available to industry a choice and for providing security in case one source has to close down for repair. Also, the need for more than one source can be argued by scaling the number of fabrication houses operating and being planned (approximately 30) in the United States using the ratio of the GNP's of the two countries or the ratio of populations. As well, geographical arguments point to more than one such facility. A number of small countries such as Austria and Yugoslavia have chip fabrication facilities. All these developments illustrate the need and the opportunity for Alberta to bring the undertaking proposed in this submission into a reality.

3. Precedents

Stanford University in the Silicon Valley has recently taken a bold

new initiative to foster the necessary infrastructure for the next stage of microelectronics development. It has established "The Center for Integrated Systems" which is integrating solid state research and fabrication with applications. This Center is a joint undertaking by Stanford, the United States Government and industry. Already, between them, they have raised \$40 million U.S. to develop the facilities and support the work of the Center for its first three years.

Similar undertakings are occurring at a number of other universities in the United States including the Massachusetts Institute of Technology, Berkeley, University of North Carolina, Arizona State University, Rensselaer Polytechnic and Carnegie-Mellon University. In Europe similarly developments are taking place in France (Grenoble) Netherlands (Delft) and Belgium.

Although Alberta needs differ to some degree from those of the areas served by the aforementioned institutions, some variation of these undertakings is mandatory for furthering the province's goals.

4. Microchip Fabrication Service

Since no fabrication facility exists at present in Canada for supplying microchips on the open market, our electronics industry is highly dependent upon microchip sources from other countries. This dependence could easily cripple the development of our electronics industry because during periods of international economic expansion those sources could become extremely limited. The foreign chip foundries would likely service companies within their boundaries first. Such an experience has already transpired. During the mid 1970's TTL low power Shottky and CMOS devices produced in the United States became scarce for firms in Canada because of the boom in the global economy at that time. Also, when a major military undertaking is pursued by a foreign country upon which we rely as a supplier of electronics devices, electronic fabrication service can be

seriously curtailed. The scarcity of the mid 1970's could easily result again if proposed programs such as the MX missile program in the United States go ahead. Military requirements of such foreign countries could dictate that their chip fabrication facilities must give first priority to their own firms with commitments to their military. This action would lead to seriously cutting the availability of microchips to Canadian industry. The lack of security of supply of microchips will very adversely affect our industry's ability to negotiate new markets.

Another crucial factor which underlines the requirement for having a fabrication facility here is the new secrecy policies in the United States and elsewhere, brought about for security reasons. The economic competition in microelectronics has become extremely intense and has generated these new policies. Already these policies have led to the withholding of important microelectronics technological information from Canadian industry and universities. This problem must be coped with if our electronics industry is to be viable.

A further reason for having this facility is to provide our industry with custom integrated circuits. More and more, industry is finding the use of standard integrated circuits unsatisfactory in coping with competitors in meeting new customer demands at low cost. When the economy is expanding, integrated circuit suppliers mainly produce standard circuit designs and just do not have the capacity for producing custom models. The suppliers devote their plants to standard design because of the large volumes ordered by users. Unless large volumes are guaranteed at the outset, the fabrication houses during periods of high demand may not be interested at all in a custom order. For these reasons, our industry will likely face, in the near future, a bottleneck in trying to purchase custom chips from foreign

suppliers. It is extremely important that we develop a fabrication source in Canada, especially for low volume custom and semi-custom chips. Also, a strong need exists in Canada to have a second source for the popular standard microchips.

One of the prime needs of industry is to have available a computer aided design service (CAD). Integrated circuit houses concentrate their efforts on standard designs and so, especially when the economy is buoyant will not provide custom design service if large volumes are not guaranteed from the outset. As a result, it is most important that this design service be available to our industry. One method of aiding this end, is to have two design centers, one located in Calgary to service the southern region of the province, and the other in Edmonton to service the northern region. Since some CAD/CAM facilities are located at the Universities of Alberta and Calgary, a logical step is to use these facilities as the core design centers for the Alberta Microelectronics Facility. The CAD/CAM facility at the University of Calgary would need a major infusion of new equipment and software; the facility at the University of Alberta will be able to initially serve as a core design center with only a few acquisitions of primarily software and with additional staff. This matter will be expanded upon in Section 6.1.4.

A growing need exists today in Canada for having a marked increase in chip fabrication service for our educational institutions. At present, each university can have up to two VLSI chips (8 designs) built per year at the Bell Northern Research Laboratories under a program sponsored by the Natural Sciences and Engineering Research Council. This coming term the Electrical Engineering Department at the University of Alberta, alone, expects to register 15 to 30 students in a course on VLSI chip design, which

could readily lead to requiring a comparable number of designs being fabricated if the course is to offer an optimum experience for the students. Presently, the time required to produce the chips once the design is completed is six months which is far too long for students taking courses taught over three month periods.

The practical experience of having a design built and tested is extremely important in the education of a design engineer. Such experience is required if our graduates at the bachelors, masters and doctoral levels are to be at the forefront of the microelectronics technology at graduation. Graduates with such a background will be in considerable demand by our electronics industry as this field builds to become even more competitive on the world market.

In conjunction with the education program, a strong VLSI research program should be nurtured at the universities which will integrate solid state research and fabrication with applications. Such an undertaking will require the bringing together of many disciplines including solid-state physics, device fabrication, computer aided design, processing and applications. The program should have the capability of defining the applications, designing the system and chips, applying the system, fabricating the chips, integrating the system and testing the chips. This type of undertaking is a must if we are to keep abreast of the frontier developments in the microelectronics field. With the funding already provided to our researchers by agencies such as the Natural Science and Engineering Research Council and other institutions through contract research, considerable research activity can be expected to be generated in Alberta if a microelectronics fabrication facility is located in the Province.

5. A Major Initiative for Developing High Technology Industry

The establishment of a microchip fabrication facility in Alberta would be a major initiative in developing our high technology industry. Such a facility would be a focus in attracting new high technology firms and highly skilled professional workers. The expectation is that the facility would stimulate major new advances, innovations and spin offs in the electronics field. In essence, the creation of the facility would be a significant step by the Government of Alberta in building the high technology industry in the province. If Alberta aspires to have a leading role in advanced technology, the Government must introduce extra measures to realize this goal. One such measure is the founding of the Alberta Micro-electronics Facility. Such an Alberta initiative is most important. Recently, the Government of Ontario has funded six technological centers, to stimulate growth in small and medium size business. The total investment by the Government of Ontario over a five year period is expected to be \$130 million. These centers will include the Microelectronics Center located in Ottawa, the Autoparts Center in St. Catharines, the CAD/CAM Center in Cambridge and the Robotics Center in Peterborough. These measures will considerably assist Ontario's already markedly successful high technology industry. In Japan the national government has collaborated closely with Japanese forefront technology industry while making considerable investment in research and development. Everyone knows how successful this partnership in Japan has been. In the United States, government initiative to nurture high technology industry has been mandatory. For example, the Silicon Valley in California would not have developed into a world leading center in electronics without the many U.S. military and aerospace contracts let to firms in that area. Similarly, government support was required to establish advanced technology industry in the Boston area. Military contracts are not likely to be catalyst of industry in Alberta, and, as

a result, alternative government measures will be required and a micro-electronics facility, as proposed, could certainly be an extremely significant component in realizing a flourishing high technology industry in Alberta.

6. Programs to Meet the Industrial and Educational Needs of the Province

6.1 Primary Facilities

The Alberta Microelectronics Facility should undertake to establish, likely on a staged basis, the following services for meeting the industrial, educational and research needs of the Province.

6.1.1 A Laboratory Line

A laboratory should be constructed which would have the capability of fabricating small numbers of microchips, primarily research and development prototypes for industry and educational institutes with turn around times of two weeks. Here, the parameters of the processes can be adjusted and the line would serve the integrated circuit, device, and process research activities in the province.

Both the University of Alberta and the University of Calgary would be expected to make considerable use of the laboratory line. The universities would have student VLSI designs fabricated on this line. At present, we are very limited with the National Program where only 2 chips (8 designs) per year can be fabricated for each university. We foresee this number increasing at the University of Alberta to approximately 30-40 chips and a similar number could be anticipated at the University of Calgary. Also, as our faculty members become heavily involved in their research in chip design and fabrication, the expectation is that they will be heavy users of the line. Some arrangement should be made so that

student use and use for research sponsored by granting agencies like NSERC is free of cost or nominal. This arrangement might be achieved through reciprocal exchanges of services between the universities and the Alberta Microelectronics Facility or through a grant. Contract research programs would likely be charged the full commercial rates.

The new technologies program, which would be associated with the laboratory line, should include research into new types of chip design and new types of chip material such as gallium arsenide. Another area of research could be in the development of submicron size devices.

6.1.2 A Low Volume Manufacturing Line

A laboratory should be constructed which would have the capability of fabricating up to 50 wafers of microchips per day. The production would be

- i) chips for industry for prototype systems and devices
to give turn around times of a few months instead of possibly years as can be the case in Canada during periods of economic growth.
- ii) semi-custom chips for industry and educational institutes.
- iii) custom chips for industry and educational institutes.

6.1.3 A High Volume Manufacturing Line

The Alberta Microelectronics Facility should establish a manufacturing line to meet the needs of industry. The reasons for such a line are outlined in sections 4 and 5 of this report. The line would produce standard chips which are the first to become unavailable for our industry in times of high demand. As well as being a primary source, this line could, also, act as a second source which is a role of major importance to our industry. Although such a line would undoubtedly need to be

subsidized initially, it could readily become a source of income for the Facility.

6.1.4 CAD/CAM Facility

As already mentioned, a prime need of industry is to have a computer aided design service. Such a service is of equal importance to our universities for teaching and research. Already the Universities of Calgary and Alberta have capabilities in this field and these institutions could provide the core design centers for the Alberta Microelectronics Facility. To do so would require major additions of hardware and software at the University of Calgary and additions of software at the University of Alberta where a modern state of the art Computervision CAD/CAM System has just recently been purchased. The requirements for the University of Calgary will undoubtedly be addressed in the submission by Drs. Hill, Hope and Kendall.

At the University of Alberta we have attempted to assess the extent our CAD/CAM system may meet the requirements of the Alberta Microelectronics Facility knowing that typically a custom fabrication house in industry will have three color work stations available for its designers. The University of Alberta CAD/CAM system has at present eight work stations - four in color and four in black and white. Provision will be available shortly through new accessories being developed by Computervision to expand, when desired, the number of work stations to more than 30. As outlined in Appendix I, we have made very preliminary estimates that in the next few years, three work stations will be required for courses offered at the University by the Faculty of Engineering and the Alberta Microelectronics Development and Applications Center and for research programs in the Faculty. If one further work station is kept for unforeseen applications four stations will likely be available during the initial years for the requirements of

the Alberta Microelectronics Development and Applications Center for industrial use and the Alberta Microelectronics Facility. This number would appear reasonable initially for meeting the entire industrial needs of these two organizations. However, this situation could change quickly if an attempt was made to handle, for example, the VLSI designs for all Canadian universities. With our current CAD/CAM capability we only anticipate doing the designs for our university and possibly helping a few others.

We foresee that the Alberta Microelectronics Facility would arrange through the Alberta Microelectronics Development and Applications Center the time required on the University of Alberta CAD/CAM system. Naturally, before any final agreement is reached a more detailed estimate will have to be made and a contract would have to be negotiated involving the University of Alberta Central Administration, the Alberta Microelectronics Development and Applications Center and the Alberta Microelectronics Facility.

For the University of Alberta CAD/CAM system to be completely operational for the requirements of the Alberta Microelectronics Facility, the only additional purchases required are software for design automation. As well, more staff would have to be hired for the system to meet the Facility's requirements. When the time is reached that the expansion of the University of Alberta CAD/CAM system is necessary, a number of major new additions are required - the first is work stations, another is a VAX type computer for handling the increased computing demands, a further is the accessories for making the expansion possible and naturally another is more physical space along with more manpower.

6.2 Application Programs

6.2.1 Sensor Program

In conjunction with the aforementioned three lines, a program should

be undertaken to develop and manufacture semiconductor sensors. Such an undertaking would give the Alberta Microelectronics Facility a unique international role in the technology. Special emphasis should be given to sensor applications to the resource industry. Such sensors would have a ready local market in Alberta. Other important types of sensors that pertain to the Alberta scene are the biomedical group of sensors and sensors for the agricultural industry. The Facility should give high priority to producing these latter two types of sensors. Also, the program should undertake the production of sensors for robots, an extremely important component of the microelectronics technology. Another type of sensor which should be developed are those for measuring climatic and environmental (e.g. H_2S) conditions.

6.2.2 Testing and Inspection Service

The Facility should have a testing and inspection service for microelectronic devices. This service should include non-standard test equipment for testing the functions of sensors and other special devices and is especially important in the medical field where malfunction of a device could jeopardize the health of a patient. Also, in some instances it will be important to test the chips for serviceability in the Alberta environment. Reliability test facilities should be included in this program (for instance in the temperature extremes of the Canadian climate).

6.2.3 Education Program

The education program of the Facility should include providing students access to the Facility so that they can build chips they have designed. As well, the Facility could become involved in the development of end use equipment for computer aided education programs such as Plato.

Appendix I

The estimate that the University of Alberta will require in the next few years the use of three work stations on our new CAD/CAM system is based on the following study. This study includes the requirements of the Microelectronics Development and Applications Center for the Center's course offerings alone and not its needs for other areas such as industrial contracts.

At the University of Alberta we anticipate in electrical and computer engineering an enrollment of 60 undergraduate and 20 graduate students per year in courses on design using the CAD/CAM system. Possibly another 40 students per year from other engineering departments will use the system for courses. The Microelectronics Development and Applications Center anticipates using the system for 60 students per year for courses. This use, based on 40 hours per year per student, is expected to require approximately 7000 hours per year on the work stations. As well, in electrical and computer engineering we expect 10 or more faculty members and 30 graduate students using the system. For total faculty use, these numbers of faculty members and graduate students could likely be doubled. Although the total time required by these individuals is extremely hard to estimate, one might guess the number to be a further 7000 hours per year. If each work station was operating for 24 hours per day, the total time per year available on each station is 8760 hours. Possibly, a more realistic use time is 5000 hours. As a result, the uses already described (14000 hours) would likely occupy three work stations. One further work station should be reserved for unforeseen applications. Consequently, four work stations would be available for the industrial projects undertaken by the Microelectronics Development and Applications Center and for the Alberta Microelectronics Facility.

Implementation and Operations of
an Alberta Microelectronic Chip Fabrication Facility

J. Robson

The Alberta Microelectronic Centre

April 14, 1983

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1. SUMMARY

Alberta's strategy of diversification must include providing Alberta companies with the state-of-the-art tools which will enable them to compete internationally. Since product life cycles are now between 1 to 3 years, this requires that the latest in design methods and systems be used to the fullest. Many other countries and provinces are now providing a government push to stimulate the development of microelectronics and its applications. These other governments have realized that the high tech industries are the fastest growing industries and that they also offer many benefits and improved productivity to all other industry sectors. Alberta can greatly stimulate its own economy by supporting the implementation of a microelectronic fabrication facility. This would provide Alberta with a push that it needs.

This document outlines a matrix of alternatives varying from a small research silicon laboratory to a high volume production facility. Investments required range from \$14M to \$30M for each alternative over 6 years. Paybacks can range from a \$20M loss to a \$170M profit over 6 years. Alberta cities will then have a growing industry which will stimulate employment and improve exports.

2. GENERAL

The microelectronic industry is one of the highest growth industries in the world and therefore strengthening this industry in Alberta and Canada offers a multitude of benefits. Silicon valleys in California and Ottawa have demonstrated the high growth and spin-offs that can occur. Since Microsystems of Ottawa was dissolved 15 years ago staff have gone on to form over 300 electronic companies in the Ottawa area employing 18,000 people. Of the 80 high tech firms in the Ottawa area 22 were direct spin offs of Bell Northern Research. One of these companies is Gandalf, a 10 year old company, which will earn about 50 million this year. Mitel, which is 13 years young forecasts about one billion dollars revenue and 2500 staff by 1985. Another success story in the making is Orcatech who expects 32 million dollars revenue in their fifth year of operation. Many of these 300 electronic companies have diversified into many microelectronic application areas

which greatly benefit and improve the productivity of most other industry sectors.

Strategic investment by governments provides a "push" that stimulates growth and offers many indirect and direct benefits. The setting up of a major microelectronic design and fabrication facility would create the same situation in Alberta that has occurred in the Ottawa and the California silicon valleys.

The main objective to be achieved is to strengthen Canada's and Alberta's economies in a renewable high payback industry. Besides the facility being a revenue source over the long term, the largest payback is the provision of the technology to the 150 electronic companies in Alberta, to the new companies that start up or move to Alberta, and to the many other electronic companies across Canada. For the electronics companies to grow and meet the demands of the export market they must do as the leaders do, which is to incorporate the latest technologies into their products and processes. Incorporation of custom and semi-custom chips into export products is almost mandatory if Albertan and Canadian companies are to compete internationally.

Another benefit to the province and country is that applications of microelectronics would diversify into other industries such as robotics, manufacturing, the resource industry, process industries, agriculture, etc. Improved productivity in almost all industries is being achieved by using new microelectronic based tools. (eg. CAD/CAM, robotics, and CAE tools)

Security of supply of expertise and semiconductor components is also a very subtle reason for Alberta and Canada to set up its own fabrication facility. Already there is an embargo on technical information leaving the U.S.. Therefore Canada must develop its own expertise and keep up with Japan and the U.S. in at least some strategic industry sectors.

This document describes the implementation and management of a state-of-the-art silicon fabrication facility and microelectronic design facility. This fabrication and design facility must be very modern so Alberta and Canada can compete internationally. It must be kept up-to-date and produce quality chips. By keeping the facility up-to-date it will be much easier to import world class personnel for the facilities.

3. MICROELECTRONIC DESIGN FACILITIES

An article in a recent Electronics magazine (Aug. 11, 1983; P107) described new design methodologies used at California's Institute of Technology.

"A 16 bit microprocessor chip was defined in one week, and specified and compiled in half of a day using just 10 minutes of computer time."

The state-of-the-art in design equipment and methods has greatly changed over the last few years and is continuing to change as described above. To successfully export products companies must use the latest in CAD/CAM, silicon compilers, design workstation technologies and design techniques. The amount of this technology and methodology that exists in Alberta is negligible. Yet almost all the international companies exporting a large quantity of high tech products are committed to using it. In high growth technology companies designers can now go right to custom chips instead of building mock-up units and printed circuit boards.

The importance and the growth of the custom and semi-custom chip markets is defined in the Feb. 10, 1983 issue of Electronics. Semi-custom chips (standard cells) are expected to have the highest annual growth rate for 1983 to at least 1986 (62%). This can be compared to gate arrays (41%) and custom chips (8%).

A major effort must be made to train industry, educators and students and the design tools must be easily accessible. To accomplish this a Microelectronic Design Facility is required. It will consist of expertise and equipment which can be distributed to other design centres, universities and individual companies. To obtain the greatest benefits for our economy, companies from all over Canada must be able to easily and quickly get their products designed and their chips fabricated.

To make the microelectronic design facility flexible and of maximum benefit, it will support not only chip design but also design of printed circuit boards and hybrid components. These technologies must also be state-of-the-art and available to companies to develop their products. To support this a large computing facility is required for designers, researchers and the production and process engineers.

These design tools would include a large host computer system and multiple remote design stations. The software will enable the operator to perform the following functions: system design, schematic capture, logic simulation, net list generation, chip layout, automatic route and place, circuit simulation, design rule checks,

test generation and pattern generation.

A large education and training program is required to assist design engineers and students in using these new techniques. Extensive facilities will be available in Calgary and Edmonton. They will be connected by way of communication links back to the main design and fabrication facility. Other design centres on a smaller scale can be set up across Canada by interested groups. This should be encouraged so the facility is efficiently utilized.

4. MICROELECTRONIC FABRICATATION FACILITY

This section describes 3 different types of fabrication facilities which can be implemented independently or in parallel. Also for each type of facility 3 levels of cost are defined. The more complex lines require more equipment, throughput, automation, and staff. Each fabrication line is itemized as follows:

a) Laboratory Line- This line would be used for research and for training university students. Researchers and process engineers would concentrate on new equipment and advanced techniques. It provides a means for training and to transfer technology to the other lines as well as to reasearch new processes and special types of chips, such as sensors. This line would also be used to run very small volumes and prototype chips. It would be located at or near a university in Alberta.

b) Low Volume Production Line - This line will satisfy the main chip requirements of industry and universities. It is a small production line with fixed processes. It can handle between 20 and 100 designs per year and will produce from 50 to 300 wafers per day. The technology to be used for this line will be at least 3 to 5 micron and does not have to be state-of-the-art. Primarily custom and semi-custom chips will be manufactured on this line.

c) High Volume Production Line- This line will be more automated and will handle more wafers. New devices will be fabricated as the market demand and contracts are defined. It is recommended that we license standard technology so the facility can second source other manufacturers.

These silicon fabrication lines will use CMOS and NMOS technology which are the mainstream technologies to which many large semiconductor manufacturers are committing. CMOS technology consumes the least power of all other technologies and is easier to design than other technologies. Electronics is becoming so small that the

portability of hand held computers and terminals, is creating a market niche that will make the CMOS operation even more viable commercially. Also this technology is very well suited to Alberta's needs of extremes of temperature and operation in remote places.

The high volume production line will be committed to high demand components such as memory devices and microprocessor chips. Tables 1 and 2 illustrate the growth and consistency of markets for these two popular devices. Notice the 2 year cycles for memory components and the 3 year cycle for the microprocessor components. There is consistently a 2 year lag to implement these components into CMOS technology. Taking into account this lag and the fact that there will be a much larger demand for CMOS in the future for portable computers, there are large markets for chips being developed today, till at least 1989.

TABLE 1
DEVELOPMENT OF MEMORY CHIPS

MEMORY SIZE	ANNOUNCEMENT YEAR	MATURITY YEAR	PHASED OUT
1024	1974	1976	1979
4096	1976	1978	1981
16384	1978	1980	1983
65536	1980	1982	1985
262144	1982	1984	1987

TABLE 2
DEVELOPMENT OF MICROPROCESSOR CHIPS

SIZE (BITS)	ANNOUNCEMENT YEAR	MATURITY YEAR	PHASED OUT
4	1973	1976	1979
8	1976	1979	1982
16	1979	1981	1984
32	1981	1984	1987

5. OTHER SUPPORT PROGRAMS

Three major areas require full support to ensure the success of the design and fabrication facility. These areas

are educational programs, industrial support and encouragement programs, and research programs. The authors are aware that provincial programs are under consideration which may support these areas. Therefore these areas are only briefly discussed.

Education programs must be upgraded in the educational institutions and in industry. As discussed above, within the next few years designers will be using different tools and techniques for designing large complex chips. These methods must be available so all companies have the tools to quickly design and implement products that can compete internationally. Educational institutions must train a new breed of computing scientists, engineers, and computer engineers.

Industrial assistance programs are required to assist the small and medium sized companies in using the design and fabrication facilities. Various risk capital, funding assistance, and tax incentive programs would provide the leverage required for small Alberta and Canadian companies to meet world markets.

Research programs are also required to ensure that the design and fabrication facilities are continuously updated with state-of-the-art equipment and methods. Research grants and the sharing of joint industry-university positions will complement this proposal.

6. SCHEDULE

The time line of activities will vary according to the type of line or lines which are implemented. The planning period will take between 6 to 9 months to design the facility. The ordering and the installation of equipment can take between 6 and 12 months. Then it can take 3 to 5 months to test your facility so it produces quality chips. One possibility is to use a design and support team who have installed facilities before. One of the most automated 3 micron lines in the US was made operational in 9 months. Table 3 summarizes the implementation time for each of the 9 alternative lines.

7. IMPLEMENTATION

To implement a microelectronic design facility and a silicon foundry will take considerable detailed planning.

As there is minimal expertise in this area within the province, experts must be brought into Alberta. Various alternatives do exist. MOSAID, a high technology firm in Ottawa is a world class leader in the design and implementation of CMOS memory devices. Much of the CMOS memory expertise in North America in state-of-the-art memories have worked with or have come from MOSAID. MOSAID'S clients are many of the large CMOS semiconductor manufacturers around the world. Personnel at MOSAID have also done the full planning for 2 foundries in the United Kingdom. At present this company has offers from other countries to set up a foundry. Also MOSAID has been developing the world leading CMOS memories (static 64K and 256K memories).

The above points illustrate that there is expertise in Canada. Another alternative is to use or hire expertise from the U.S.. Still another very viable method to start up the planning and implementation process is to align Alberta closely with existing silicon foundry expertise, such as; Northern Telecom, Mitel, Siltronic, National Semiconductor, IMP, Motorola, etc.

The most crucial decisions to be made will be during the planning period. Selection of the site, equipment, and the key personnel will be important. Therefore a knowledge of the world situation, demands and future growth patterns in microelectronics will be mandatory.

Once this proposal is accepted in principal consultants should be brought in to provide more initial general direction and the detail planning.

Another approach is to obtain joint funding for the National Facility which will be located in Alberta. Alternatives that exist are NRC, the Federal Government, Industry or another Province. Participation can be very advantageous to all parties in setting up many design centres. These centres are where most of the indirect industry benefits will be obtained. For example small innovative companies now have the tools and potential to become another Mitel or Northern Telecom. Therefore each province could and should be very interested in setting up their own design centres.

The authors feel that if a world class facility is set up in Alberta, it will be much easier to attract world class experts.

8. MANAGEMENT STRUCTURE

Strong management is the key to implementing and operating the proposed facilities. It must be run professionally as a business and it must have a profit motive. A recommended management structure of the facilities is to have a Director of the Facilities report to a Board of Directors. The Board must have strong representation from Canadian and Albertan industries and any other major participants. There must always be a strong input of international awareness and representation.

Within the organizational structure mechanisms must be in place to coordinate industry, Universities and design centres.

9. COSTS AND ALTERNATIVES

Details and assumptions for each of the fabrication lines are itemized below. Assumptions which are common to each of the alternatives are as follows:

- average salary and overhead for the first year is \$70000.
- inflation rate on salaries are 10% per year.
- installation costs are 10% of all capital equipment costs.
- equipment maintenance and depreciation is 20% of the accumulated capital expenditures.
- revenues for each new chip designed is \$10000.

Details of each of the lines are compared in Table 3. It provides a comparison of the following items:

- cost of fabrication equipment (x1000)
- cost of CAD equipment (x1000)
- cost of clean room (x1000)
- cost of licensing agreements (x1000)
- selling cost of the chips
- direct material costs of the chip
- number of custom chips designed per year
- size in inches of the wafer
- number of chips (die) assumed per wafer
- yield of good chips per wafer in percent
- number of wafers produced per week
- number of chips produced per week
- total number of personnel
- total cost of operation (x1000)
- number of years to a positive yearly cash flow
- number of years for a return on investment
- profit(loss) after 6 years (x1000)
- months of planning time required
- months of installation time required
- months of test time required

Figures 4 to 12 define the cash flow for each of the alternatives. Figure 13 shows the sixth year profit picture for each of the alternatives. Below each facility alternative is briefly described as to how it differs from others.

9.1 Laboratory Line - Low Complexity

This line is the lowest cost and will be used in an existing building. It is intended for student use mainly. It is a manual system.

9.2 Laboratory Line - Medium Complexity

This line has more automated equipment and has a few more processes for development of custom sensors.

9.3 Laboratory Line - High Complexity

This line will have some state-of-the-art equipment for research. It will include an e-beam photolithography unit and some gallium arsenide process equipment. Also more sophisticated CAD software will be purchased.

9.4 Low Volume Production Line - Low Complexity

This line has a mask maker, more automated equipment for a fixed process, and more testing and characterisation equipment. Also more money is spent on the process so it is more controlled and so it is an industry standard.

9.5 Low Volume Production Line - Medium Complexity

This line has more equipment to improve throughput. It will process 4 inch wafers instead of 3 inch as in the previous configurations. Also this line will include a large Fairchild type of automated test system.

9.6 Low Volume Production Line - High Complexity

More automated equipment and an e-beam unit will be added to this line. This line would be very similar to the Low Complexity, High Volume Production Line.

9.7 High Volume Production Line - Low Complexity

This system is very similar to the high complexity line described above.

9.8 High Volume Production Line - Medium Complexity

More line equipment is added to improve the throughput.

9.9 High Volume Production Line - High Complexity

Again, more equipment and automated handling systems are incorporated into the line for faster and cheaper chip production.

Figure 3
Comparison of Fabrication Line Alternatives

ITEM/NAME	LAB1	LAB2	LAB3	LOPRO1	LOPRO2	LOPRO3	HIPRO1	HIPRO2	HIPRO3	
BUILDING				3000	3000	3000	3000	3000	3000	} x10
FAB EQUIP	2000	3000	6000	3500	5500	7800	7800	11800	17400	
CAD EQUIP	2000	2000	3000	3000	3000	3000	3000	3000	3000	
CLEAN ROO	200	400	600	200	400	600	400	600	1000	
LICENSES	1000	1000	1000	2000	2000	2000	2000	2000	2000	
CHIP SELL	20	20	20	20	15	10	10	6	3	
CHIP COST	10	10	10	7	5	3	3	2	1	
CHIP DESI	20	40	40	20	60	60	60	60	60	
WAFER SIZ	3	3	3	3	4	4	4	4	4	
DIE/WAFER	100	100	100	100	200	300	300	300	300	
YIELD %	5	5	5	7	7	10	10	10	10	
WAFER/WEE	80	130	130	600	1400	2000	2000	7000	20000	
CHIP/WEEK	400	660	660	4000	20000	60000	60000	200000	600000	
PERSONNEL	8	10	14	12	16	20	20	48	84	
TTL COST	14765	17805	26775	25815	31265	37445	37445	57065	82550	x10
CASH +VE	no	no	no	3	3	3	3	2	2	
ROI IN YR	no	no	no	no	8	5	5	4	4	
BAL. 6YRS	-13219	-15009	-23979	-13209	15681	55501	55501	120881	179396	x10
PLAN TIME	6	6	7	7	7	7	8	8	8	
INSTL TIM	5	6	6	9	9	11	11	12	12	
TEST TIME	3	3	3	3	4	4	4	5	5	

Figure 4
Laboratory Line - Low Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	350	616	672	736	808	888	4070
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	200	570	570	570	570	570	3050
INSTALLATI	200	370	0	0	0	0	822
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	875	1806	1492	1556	1628	1708	9065
BUILDING							0
CAD CAPITA	2000						2000
OUTREACH C		500					500
FOUNDRY CA		3200					3200
TOTAL INVE	2000	3700	0	0	0	0	5700
TOTAL BUDG	2875	5506	1492	1556	1628	1708	14765
REVENUES	30	90	370	600	600	600	
COST OF SA	4	20	120	200	200	200	
BALANCE	-2849	-5436	-1242	-1156	-1228	-1308	
ACC.CASH	-2849	-8285	-9527	-10683	-11911	-13219	
CHIPS OUT		2	12	20	20	20	
CHIP DESXI	3	5	13	20	20	20	
PERSONNEL							
ADMINISTRA	1	1	1	1	1	1	
CAD OPERAT	2	2	2	2	2	2	
FOUNDRY OP	2	5	5	5	5	5	
TOTAL PERS	5	8	8	8	8	8	
RATE	70	77	84	92	101	111	

Figure 5
Laboratory Line - Medium Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	420	770	840	920	1010	1110	5070
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	320	690	690	690	690	690	3770
INSTALLATI	320	370	0	0	0	0	994
DATA CENTR	25	50	50	50	50	50	275
TOTAL OPER	1185	2080	1780	1860	1950	2050	10905
BUILDING							0
CAD CAPITA	2000						2000
OUTREACH C		500					500
FOUNDRY CA	1200	3200					4400
TOTAL INVE	3200	3700	0	0	0	0	6900
TOTAL BUDG	4385	5780	1780	1860	1950	2050	17805
REVENUES	30	140	850	1000	1000	1000	
COST OF SA	4	20	300	300	300	300	
BALANCE	-4359	-5660	-1230	-1160	-1250	-1350	
ACC. CASH	-4359	-10019	-11249	-12409	-13659	-15009	
CHIPS OUT		2	30	30	30	30	
CHIP DESXI	3	10	25	40	40	40	
PERSONNEL							
ADMINISTRA	1	1	1	1	1	1	
CAD OPERAT	2	2	2	2	2	2	
FOUNDRY OP	3	7	7	7	7	7	
TOTAL PERS	6	10	10	10	10	10	
RATE	70	77	84	92	101	111	

Figure 6
Laboratory Line - High Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	490	1078	1176	1288	1414	1554	7000
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	640	1110	1110	1110	1110	1110	6190
INSTALLATI	640	470	0	0	0	0	1429
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	1895	2908	2536	2648	2774	2914	15675
BUILDING							0
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	3400	4200					7600
TOTAL INVE	6400	4700	0	0	0	0	11100
TOTAL BUDG	8295	7608	2536	2648	2774	2914	26775
REVENUES	30	140	850	1000	1000	1000	
COST OF SA	4	20	300	300	300	300	
BALANCE	-8269	-7488	-1986	-1948	-2074	-2214	
ACC.CASH	-8269	-15757	-17743	-19691	-21765	-23979	
CHIPS OUT		2	30	30	30	30	
CHIP DESXI	3	10	25	40	40	40	
PERSONNEL							
ADMINISTRA	1	1	1	1	1	1	
CAD OPERAT	2	3	3	3	3	3	
FOUNDRY OP	4	10	10	10	10	10	
TOTAL PERS	7	14	14	14	14	14	
RATE	70	77	84	92	101	111	

Figure 7
Low Volume Production Line - Low Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	490	924	1008	1104	1212	1332	6070
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	650	920	920	920	920	920	5250
INSTALLATI	650	270	0	0	0	0	1242
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	1915	2364	2178	2274	2382	2502	13615
BUILDING	3000						3000
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	3500	2200					5700
TOTAL INVE	9500	2700	0	0	0	0	12200
TOTAL BUDG	11415	5064	2178	2274	2382	2502	25815
REVENUES	30	2080	4200	4200	4200	4200	
COST OF SA	4	700	1400	1400	1400	1400	
BALANCE	-11389	-3684	622	526	418	298	
ACC.CASH	-11389	-15073	-14451	-13925	-13507	-13209	
CHIPS OUT		100	200	200	200	200	
CHIP DESX1	3	8	20	20	20	20	
PERSONNEL							
ADMINISTRA	1	1	1	1	1	1	
CAD OPERAT	3	5	5	5	5	5	
FOUNDRY OP	3	6	6	6	6	6	
TOTAL PERS	7	12	12	12	12	12	
RATE	70	77	84	92	101	111	

Figure 8

Low Volume Production Line - Medium Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	560	1232	1344	1472	1616	1776	8000
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	650	1140	1140	1140	1140	1140	6350
INSTALLATI	650	490	0	0	0	0	1545
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	1985	3112	2734	2862	3006	3166	16865
BUILDING	3000						3000
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	3500	4400					7900
TOTAL INVE	9500	4900	0	0	0	0	14400
TOTAL BUDG	11485	8012	2734	2862	3006	3166	31265
REVENUES	50	7650	15250	15400	15500	15600	
COST OF SA	4	2500	5000	5000	5000	5000	
BALANCE	-11439	-2862	7516	7538	7494	7434	
ACC.CASH	-11439	-14301	-6785	753	8247	15681	
CHIPS OUT		500	1000	1000	1000	1000	
CHIP DESX1	5	15	25	40	50	60	
PERSONNEL							
ADMINISTRA	1	2	2	2	2	2	
CAD OPERAT	3	5	5	5	5	5	
FOUNDRY OP	4	9	9	9	9	9	
TOTAL PERS	8	16	16	16	16	16	
RATE	70	77	84	92	101	111	

Figure 9
Low Volume Production Line - High Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	630	1540	1680	1840	2020	2220	9930
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	900	1390	1390	1390	1390	1390	7850
INSTALLATI	900	490	0	0	0	0	1888
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	2555	3670	3320	3480	3660	3860	20545
BUILDING	3000						3000
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	6000	4400					10400
TOTAL INVE	12000	4900	0	0	0	0	16900
TOTAL BUDG	14555	8570	3320	3480	3660	3860	37445
REVENUES	50	10150	30250	30400	30500	30600	
COST OF SA	4	3000	9000	9000	9000	9000	
BALANCE	-14509	-1420	17930	17920	17840	17740	
ACC.CASH	-14509	-15929	2001	19921	37761	55501	
CHIPS OUT		1000	3000	3000	3000	3000	
CHIP DESX1	5	15	25	40	50	60	
PERSONNEL							
ADMINISTRA	1	2	2	2	2	2	
CAD OPERAT	3	5	5	5	5	5	
FOUNDRY OP	5	13	13	13	13	13	
TOTAL PERS	9	20	20	20	20	20	
RATE	73	77	84	92	101	111	

Figure 10
High Volume Production Line - Low Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	630	1540	1680	1840	2020	2220	9930
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	900	1390	1390	1390	1390	1390	7850
INSTALLATI	900	490	0	0	0	0	1888
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	2555	3670	3320	3480	3660	3860	20545
BUILDING	3000						3000
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	6000	4400					10400
TOTAL INVE	12000	4900	0	0	0	0	16900
TOTAL BUDG	14555	8570	3320	3480	3660	3860	37445
REVENUES	50	10150	30250	30400	30500	30600	
COST OF SA	4	3000	9000	9000	9000	9000	
BALANCE	-14509	-1420	17930	17920	17840	17740	
ACC.CASH	-14509	-15929	2001	19921	37761	55501	
CHIPS OUT		1000	3000	3000	3000	3000	
CHIP DESX1	5	15	25	40	50	60	
PERSONNEL							
ADMINISTRA	1	2	2	2	2	2	
CAD OPERAT	3	5	5	5	5	5	
FOUNDRY OP	5	13	13	13	13	13	
TOTAL PERS	9	20	20	20	20	20	
RATE	70	77	84	92	101	111	

Figure 11
High Volume Production Line - Medium Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	1400	2926	4032	4416	4848	5328	22950
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	1100	1790	1790	1790	1790	1790	10050
INSTALLATI	1100	690	0	0	0	0	3410
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	3725	5656	6072	6456	6888	7368	36165
BUILDING	3000						3000
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	8000	6400					14400
TOTAL INVE	14000	6900	0	0	0	0	20900
TOTAL BUDG	17725	12556	6072	6456	6888	7368	57065
REVENUES	50	24150	60250	60400	60500	60600	
COST OF SA	4	8000	20000	20000	20000	20000	
BALANCE	-7679	3594	34178	33944	33612	33232	
ACC.CASH	-7679	-14085	20093	54037	87649	120881	
CHIPS OUT		4000	10000	10000	10000	10000	
CHIP DESX1	5	15	25	40	50	60	
PERSONNEL							
ADMINISTRA	2	3	3	3	3	3	
CAD OPERAT	3	5	5	5	5	5	
FOUNDRY OP	15	30	40	40	40	40	
TOTAL PERS	20	38	48	48	48	48	
RATE	70	77	84	92	101	111	

Figure 12
High Volume Production Line - High Complexity

YEAR	1	2	3	4	5	6	TOTAL
SALARIES	1400	4543	7056	7728	8484	9324	38535
OUTREACH T	100	200	200	200	200	200	1100
MAIN & DEP	1400	2390	2390	2390	2390	2390	13350
INSTALLATI	1400	990	0	0	0	0	5299
DATA COMMU	25	50	50	50	50	50	275
TOTAL OPER	4325	8173	9696	10368	11124	11964	55650
BUILDING	3000						3000
CAD CAPITA	3000						3000
OUTREACH C		500					500
FOUNDRY CA	11000	9400					20400
TOTAL INVE	17000	9900	0	0	0	0	26900
TOTAL BUDG	21325	18073	9696	10368	11124	11964	82550
REVENUES	50	30150	90250	90400	90500	90600	
COST OF SA	4	10000	30000	30000	30000	30000	
BALANCE	-21279	2077	50554	50032	49376	48636	
ACC.CASH	-21279	-19202	31352	81384	130760	179396	
CHIPS OUT		10000	30000	30000	30000	30000	
CHIP DESX1	5	15	25	40	50	60	
PERSONNEL							
ADMINISTRA	2	4	4	4	4	4	
CAD OPERAT	3	5	5	5	5	5	
FOUNDRY OP	15	50	75	75	75	75	
TOTAL PERS	20	59	84	84	84	84	
RATE	70	77	84	92	101	111	

Figure 13
Sixth Year Profit (loss)
Position for Fabrication
Line Alternatives

